

Research Article

## Mitigation of *Aspergillus flavus* and its aflatoxins in wheat grains by gamma irradiation and calcium oxide

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**Abstract:** *Aspergillus flavus* is one of the important species of molds that can produce toxins during improper storage of wheat grains. In this study, different amounts of calcium oxide (0, 0.5, and 1%) were mixed with wheat samples containing mold spores. After 20 days, the samples were exposed to gamma radiation (0, 5, 10, 15, and 20 KGy). The presence of *A. flavus*, Aflatoxin B<sub>1</sub> (AFB<sub>1</sub>), aflatoxin B<sub>2</sub> (AFB<sub>2</sub>), aflatoxin G<sub>1</sub> (AFG<sub>1</sub>), and aflatoxin G<sub>2</sub> (AFG<sub>2</sub>) was assessed in samples. The results indicated that the effects of calcium oxide, gamma irradiation, and their interactions were significant on *A. flavus*, AFB<sub>1</sub>, and AFB<sub>2</sub> contamination. Furthermore, other toxins like AFG<sub>1</sub> and AFG<sub>2</sub> were not found in the samples. An additional reduction in AFB<sub>1</sub> and AFB<sub>2</sub> was observed when irradiation was accompanied by CaO, and the maximum inhibition of aflatoxin production was achieved at 0.5% CaO. Consequently, based on the standard maximum limit of 10 KGy for cereals, the findings of this research suggest that 0.5% of calcium oxide and 10 KGy of irradiation could be applied in the storage of wheat grains to mitigate *A. flavus*, AFB<sub>1</sub>, and AFB<sub>2</sub>.

**Keywords:** *Aspergillus flavus*, aflatoxins, wheat grains, gamma radiation, calcium oxide

### Introduction

Wheat has been considered as one of the most important sources of food for human consumption, which is rapidly infected with *Aspergillus flavus* due to poorly maintained storage conditions. The growth of this fungus causes the production of aflatoxins such as B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub>, and G<sub>2</sub>, in addition to food degradation and wheat spoilage (Whitaker, 2003). Furthermore, the presence of these toxins in flour and the products thereof and their consumption can cause

acute liver injury, liver cirrhosis, tumor induction, and teratogenic and carcinogenic effects (IARC, 2012). Thus, to reduce or eliminate the *A. flavus* and its toxins, several methods have been studied. Some methods dealt with the use of chemicals such as ozone (Savi *et al.*, 2015), calcium hydroxide (Elias-Orozco *et al.*, 2002), sodium bicarbonate and potassium carbonate (Amézqueta *et al.*, 2008), CO<sub>2</sub> (Mahbobinejhad *et al.*, 2019) and their effectiveness in the elimination of aflatoxins and other mycotoxins were evaluated. New techniques such as microwave heating (Kaur *et al.*, 2014), UV-C radiation (Ghanghro *et al.*, 2016), and pulsed electric field (Vijayalakshmi *et al.*, 2018) was also used, which caused the destruction of aflatoxin in wheat seeds. Furthermore, gamma radiation is known as a method of control and reduction of fungal toxin

Handling Editor: Naser Safaie

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Received: 23 March 2020, Accepted: 11 December 2020

Published online: 14 February 2021

production. In one research, the 5 KGy gamma-ray irradiation process in wheat resulted in a considerable decrease in AFB<sub>1</sub> and was accompanied by a reduction in protein and an increase in carbohydrates (Aziz *et al.*, 2004).

It was also reported that irradiation doses (5-20 KGy) and wheat moisture levels (9-17%), did not cause significant effects on the reduction in AFB<sub>1</sub> concentration, whereas irradiation caused a decrease in the T-2 toxin (Hooshmand *et al.*, 1995). The complete elimination or decomposition of aflatoxins requires a high radiation dose (due to their resistance to gamma radiation), the high-level radiation causes the decomposition of various food components in cereal grains (Siddhuraju *et al.*, 2002) therefore, it is recommended that alternative methods or materials be provided to increase the efficacy of irradiation for food decontamination and shelf-life extension (Pankaj *et al.*, 2018). For this purpose, some attempts have been carried out. In one research, the combined effect of potassium sorbate and irradiation on the maintenance of strawberry quality was assessed (Al-Kuraieef *et al.*, 2019) and in another study, the interaction effect of radiation treatment and modified atmosphere packaging (MAP) on the shelf-life of fresh figs was reported (Waghmare *et al.*, 2018).

Calcium oxide is considered one of the important compounds in the food industry that is mainly used for purification processes. This material reacts with water to produce calcium hydroxide, which is used through heating to treat and soften the corn pericarp in countries like Mexico (known as the nixtamalization process). Also, a study has shown that calcium oxide significantly reduces mycotoxins (Schaarschmidt *et al.*, 2019).

However, despite separate studies on the effect of calcium oxide and radiation on the decomposition of fungal toxins in cereals, there has been no report on the simultaneous influence of calcium oxide and radiation in cereals to reduce the growth of *A. flavus* mold and its toxins production. Therefore, the purpose of this study was to assess the suitable gamma dose as well as to identify the effect of

gamma irradiation and calcium oxide on *A. flavus* population and aflatoxins concentration.

## Materials and Methods

Wheat seed (cultivar Number N-87-20, Golestan Agricultural and Natural Resources Research and Education Center, Iran), *A. flavus* (code: PTCC5004, Pasteur Institute of Iran), culture medium (Sabouraud 4% dextrose agar, Merck, Germany), calcium oxide (Calcium oxide powder; assay: 95%; SRL Co, India).

## Sample preparation

Wheat grains without apparent physical damage, insect infestation, and aflatoxin contamination (confirmed by the Golestan Agricultural and Natural Resources Research and Education Center, Gorgan, Iran) were selected and transferred to the laboratory in sterile plastic bags. The specimens were disinfected by immersion in 5% H<sub>2</sub>O<sub>2</sub> solution for 5 minutes and washed 3 times with sterile distilled water. Following this, the moisture content of the samples was adjusted to 25% (w/w).

## Preparation of the fungal suspension for inoculation

The purchased strain of *A. flavus* was restored in Sabouraud Dextrose Agar medium (sterilized by Autoclave, model; DS8000255, Behdad, Iran), to form a conidial suspension of the mold. To impregnate the samples with fungal colonies of *A. flavus*, their 7-day colonies were employed. For harvesting, the fungal colonies, 5 ml of normal sterile saline was poured into the plates and mixed for 15 min at 100 rpm in the rotator shaker (VDRL, Bazianlab, Iran). Using Hemocytometric laminae, 10<sup>6</sup> fungal spores per ml were prepared for inoculum. Then, for sample inoculation, each of 200 g wheat (weighted by scale, model; TE15025, Sartorius, USA) was sprayed with 2 ml fungal suspension. The samples were then incubated for 20 days at 25 °C (using a refrigerator incubator model; aqualytic Faks-1802, Germany) with a relative humidity of 97-98% (Refai *et al.*, 1996). Before incubation, the

contaminated wheat was uniformly sprayed with CaO powder to the determined concentrations of 0.5% and 1% (w/w).

### Samples radiation

The inoculated wheat grains were exposed to different doses of 0, 5, 10, 15, and 20 KGy, emitted by the Cobalt-60 (Dose rate 4.9 Gy/min, gamma cell model; Issledovapel-Px30, Russia) at Iran's Atomic Energy Organization, Nuclear Agriculture Research Institute, Karaj, Iran.

### Enumeration of *A. flavus* colonies

*Aspergillus flavus* colony counts were performed by standard reference methods (ISO, 2008). For the detection of aflatoxins in the samples, 25 g of each sample was ground with a powder mixer, then extracted with methanol containing 4% KCl. The extracts were purified with a 30% ammonium solution and the extraction of aflatoxins was undertaken with the addition of chloroform. The toxins were identified and determined using high-performance liquid chromatography (Waters E2695). The detector was a multi-wavelength fluorescence detector (Waters 2475) and was used in the following conditions: excitation of 362 nm, emission of 426 nm for aflatoxins B<sub>1</sub> and B<sub>2</sub>, and emission of 465 nm for aflatoxins G<sub>1</sub> and G<sub>2</sub>. The samples were analyzed at the H<sub>2</sub>O/ACN/MeOH (6:2:3 v/v/v) mobile phase, 60- $\mu$ l injection volume, and a flow rate of 2 ml/min and 40 °C using a 100 mm  $\times$  4.6 mm id Chromolith analytical column (Phenomenex Inc., USA) (16050 ISO, 2003).

### Statistical analysis

A full factorial designed experiment was conducted to examine the calcium oxide and gamma irradiation on the control of aflatoxins. The factorial design consisted of all possible combinations of levels for all factors. In this experiment the first factor was calcium oxide consisted of three-level (0, 0.5, and 1%) and gamma irradiation at five levels (0, 5, 10, 15, and 20 KGy). When factors were significantly different, the treatments were grouped by Tukey's test at  $P < 0.05$ . The statistical analysis was performed by SPSS version 16.0 The

Generalized Linear Model was conducted by the response surface method (Design-Expert V. 10) to describe the distinctive and interactive effects of calcium oxide and gamma irradiation on *A. flavus*, AFB<sub>1</sub>, AFB<sub>2</sub>, AFG<sub>1</sub>, and AFG<sub>2</sub>.

## Results

### Effect of calcium oxide and irradiation on *A. flavus* population

In this study, the addition of calcium oxide has a significant effect on the amount of *A. flavus* ( $F = 20.098$ ;  $df_v = 2$ ;  $df_e = 30$ ;  $p < 0.01$ ). This effect is dependent upon the quantity of calcium oxide. For example, in non-irradiated samples containing 0.5% and 1% calcium oxide, *A. flavus* increased by 39.9% and 12.73%, respectively (compared to the control). In the irradiation analysis, its negative effect on the population of *A. flavus* ( $F = 548.77$ ;  $df_v = 4$ ;  $df_e = 30$ ;  $p < 0.001$ ) was determined, as the population was reduced by increasing the intensity of the irradiation, so that the highest reduction (84 to 85%) was recognized at 20 KGy (Table 1). The analysis of variance also showed that in the mildew population, there was a significant interaction between calcium oxide and irradiation ( $F = 7.74$ ;  $df_v = 8$ ;  $df_e = 30$ ;  $p < 0.001$ ). As shown in Table 1, fluctuations in the population of mold are notable, as they decrease by increasing the intensity of irradiation, but a change occurred in the presence of calcium oxide. While the average reduction in the mold in the irradiation process was 49.07%, this loss in the presence of 0.5% and 1% calcium oxide was 41.15% and 43.7%, respectively (Table 1). Concerning fungal loading, the non-irradiated sample containing 0.5% calcium oxide (No. 6) revealed the maximum presence of *A. flavus* (509333 cfu/g), but the minimum values were detected in samples 5, 10, and 15.

Depending on the fungal population, the treatments were categorized into five groups. The largest group comprised seven samples (No. 3, 4, 5, 9, 10, 14, and 15), and the smallest group consisted of a single treatment (No. 6). Table 1 shows the mean *A. flavus* values and the similarities or differences between treatments.

**Table 1** Means and standard deviation values of *A. flavus* population, Aflatoxin B<sub>1</sub> and B<sub>2</sub> concentrations in wheat.

Samples	CaO (%)	Irradiation dose (KGy)	<i>A. flavus</i> (Cfu × 10 <sup>3</sup> /g) <sup>1</sup>	<i>A. flavus</i> Reduction (%)	AFB <sub>1</sub> (ppb) <sup>1</sup>	AFB <sub>1</sub> Loss (%)	AFB <sub>2</sub> (ppb) <sup>1</sup>	AFB <sub>2</sub> Loss (%)
1	0	0	366.0 ± 25.1 <sup>b</sup>	0	8802 ± 58 <sup>b</sup>	0	1241 ± 6 <sup>a</sup>	0
2	0	5	252.0 ± 22.1 <sup>c</sup>	31.06	4624 ± 57 <sup>e</sup>	47.47	1033 ± 15 <sup>b</sup>	16.71
3	0	10	125.0 ± 18.0 <sup>de</sup>	65.83	4180 ± 72 <sup>f</sup>	52.51	936 ± 9 <sup>c</sup>	24.56
4	0	15	93.3 ± 15.3 <sup>e</sup>	74.28	3757 ± 81 <sup>g</sup>	57.32	833 ± 12 <sup>d</sup>	32.86
5	0	20	53.3 ± 10.4 <sup>ef</sup>	85.36	3257 ± 51 <sup>i</sup>	63.00	672 ± 8 <sup>e</sup>	45.86
Average (sample 1-5)				49.07		44.06		30.00
6	0.5	0	509.3 ± 41.0 <sup>a</sup>	-39.90	6307 ± 31 <sup>c</sup>	28.34	220 ± 15 <sup>h</sup>	82.27
7	0.5	5	293.3 ± 25.2 <sup>c</sup>	19.91	3407 ± 38 <sup>h</sup>	61.30	170 ± 6 <sup>i</sup>	86.32
8	0.5	10	159.7 ± 20.0 <sup>d</sup>	56.49	2287 ± 61 <sup>j</sup>	74.02	130 ± 5 <sup>j</sup>	89.52
9	0.5	15	97.3 ± 12.5 <sup>e</sup>	73.48	1877 ± 21 <sup>k</sup>	78.68	112 ± 7 <sup>jk</sup>	90.97
10	0.5	20	55.3 ± 15.0 <sup>ef</sup>	84.65	1573 ± 25 <sup>l</sup>	82.12	87 ± 4 <sup>k</sup>	93.01
Average (sample 6-10)				41.15		64.89		88.42
11	1	0	411.7 ± 17.6 <sup>b</sup>	-12.73	9233 ± 21 <sup>a</sup>	-4.91	462 ± 20 <sup>f</sup>	62.78
12	1	5	304.3 ± 19.1 <sup>c</sup>	16.62	5637 ± 42 <sup>d</sup>	35.96	254 ± 11 <sup>g</sup>	79.50
13	1	10	162.0 ± 8.2 <sup>d</sup>	55.64	4730 ± 46 <sup>e</sup>	46.26	180 ± 8 <sup>i</sup>	85.52
14	1	15	92.7 ± 12.5 <sup>e</sup>	74.76	4190 ± 26 <sup>f</sup>	52.39	125 ± 11 <sup>j</sup>	89.89
15	1	20	57.3 ± 2.5 <sup>ef</sup>	84.25	3673 ± 31 <sup>g</sup>	58.27	90 ± 6 <sup>k</sup>	92.77
Average (sample 11-15)				43.71		37.6		82.10
Average (sample 6-15)				42.43		51.24		85.25
Total average (sample 1-15)				44.64		48.85		64.83
F			164		6599		4321	
df <sub>v</sub>			14		14		14	
df <sub>e</sub>			30		30		30	
P			< 0.0001		< 0.0001		< 0.0001	

<sup>1</sup> Values are means of three replicates ± standard deviation (SD). Values followed by the same letter are not significantly different ( $P < 0.05$ ) according to the Tukey's test.

% Loss was calculated based on the control sample (0% CaO, 0 KGy).

### Effect of calcium oxide and irradiation on AFB<sub>1</sub>

Based on the results of the variance analysis of the data, calcium oxide had a significant effect on the creation of AFB<sub>1</sub>, leading to both a decrease and increase in AFB<sub>1</sub> ( $F = 10395.5$ ;  $df_v = 2$ ;  $df_e = 30$ ;  $p < 0.001$ ). As seen in Table 1, the concentration of AFB<sub>1</sub> was reduced by 28.34% in the non-irradiated sample containing 0.5% calcium oxide, but at 1% calcium oxide the AFB<sub>1</sub> content increased by 4.91%. In the non-irradiated samples containing 0.5% calcium oxide, the lowest concentration of AFB<sub>1</sub> was observed despite the highest *A. flavus* populations. However, at the 1% concentration of calcium oxide, despite the decline in the *A. flavus* mold population, the concentration of AFB<sub>1</sub> increased by about 4.91% (compared to the control). Similar to the

calcium oxide results, the irradiation also had a significant effect on the AFB<sub>1</sub> values ( $F = 17733.35$ ;  $df_v = 4$ ;  $df_e = 30$ ;  $p < 0.001$ ), so that the AFB<sub>1</sub> content decreased with increased irradiation. In this research, there was a significant interaction ( $F = 82.94$ ;  $df_v = 8$ ;  $df_e = 30$ ;  $p < 0.001$ ) between calcium oxide and irradiation at AFB<sub>1</sub> values. As shown in Table 1, in the 0.5% calcium oxide concentration and 20 KGy intensity, the highest AFB<sub>1</sub> loss or lowest AFB<sub>1</sub> concentration was detected. While the maximum destructive effect of irradiation on AFB<sub>1</sub> was 63%, this loss reached the highest value at 0.5% calcium oxide (i.e., 82%). However, the preventative role of 1% calcium oxide in the production of AFB<sub>1</sub> was not successful. Among the treatments, non-irradiated wheat-containing 1% calcium oxide (No. 11) was dominant in AFB<sub>1</sub> (6307 ppb).

While in the sample containing 0.5% calcium oxide and 20 KGy radiation (No. 10), the lowest value of AFB<sub>1</sub> with a drop of 82% was detected. Table 1 shows average AFB<sub>1</sub> values that have been separated into 12 groups.

### Effect of calcium oxide and irradiation on AFB<sub>2</sub>

The variance analysis of the obtained data has demonstrated the effective role ( $F = 26429.37$ ;  $df_v = 2$ ;  $df_e = 30$ ;  $p < 0.001$ ) of CaO in the loss of AFB<sub>2</sub>. As shown in Table 1, there are clear changes in the AFB<sub>2</sub>. It was also determined that the radiation had a significant effect on AFB<sub>2</sub> ( $F = 1524.37$ ;  $df_v = 4$ ;  $df_e = 30$ ;  $p < 0.001$ ), such that the AFB<sub>2</sub> values were reduced by the increase in the radiation dose.

In the calcium-free group, the reduction in AFB<sub>2</sub> (16.71-45.86%) was lower than in groups containing 0.5 and 1% CaO. The role of calcium oxide in decreasing radiation intensity has been demonstrated by the analysis of the variance of the data. Table 1 clearly shows that in the presence of CaO, there is an increase in AFB<sub>2</sub> destruction. Even more, destruction was observed concomitantly with an increase in the irradiation dose. In this test, the common role of calcium oxide and irradiation in AFB<sub>2</sub> concentration was very significant ( $F = 193.09$ ;  $df_v = 8$ ;  $df_e = 30$ ;  $p < 0.001$ ). However, the role of calcium oxide was more effective than irradiation. While the average destructive effect of irradiation in AFB<sub>2</sub> was only 30%, this effect at 0.5% and 1% CaO reached the maximum value of 88.42% and 82.1%, respectively (Table 1). As shown in Table 1, depending on the reduction in AFB<sub>2</sub> levels, some of the samples treated with 0.5% and 1% calcium oxide were similar to each other. In the AFB<sub>2</sub> assay, the maximum AFB<sub>2</sub> value was detected in sample No. 1 (0% calcium oxide and 0 KGy), and the minimum value of AFB<sub>2</sub> was found in 0.5% calcium oxide and 20 KGy (sample No. 10). According to Tukey's test, treatments No. 8, 9, and 14 were in the same group and treatments No. 9, 10, and 15 were in another group (Table 1). Compared to the blank treatment, 93% of AFB<sub>2</sub> was eliminated in samples No. 10, and 15.

The average amount of degradation of AFB<sub>2</sub> in the presence of various amounts of calcium oxide and irradiation was 85.25%, whereas for AFB<sub>1</sub> and *A. flavus* it was 51.24% and 42.43%, respectively (Table 1). Results demonstrate the greater sensitivity of AFB<sub>2</sub> to calcium oxide. Table 1 shows the analysis of the AFB<sub>2</sub> value and similarities or differences between treatments according to Tukey's tests.

### Detection of AFG1 and AFG2

In this assay, AFG<sub>1</sub> and AFG<sub>2</sub> toxins were not identified in any of the treatments.

### Discussion

In this study, it was found that the addition of calcium oxide has miscellaneous effects on the amount of *A. flavus*. These effects vary depending on the amount of calcium oxide since optimal CaO values have led to increased mold growth, due to the role of calcium in improving metabolism and calcium supply (Viquez *et al.*, 1994). But at high calcium oxide concentration, the reduction in *A. flavus* population is associated with an increase in the concentration of calcium ions in cytotells, which is toxic to fungi. Compared to the present study, a much lower concentration of calcium (300 ppm calcium chloride) was reported as a growth prevention factor for *Botrytis cinerea* (Boumaaza *et al.*, 2015).

In the radiation assessment, *A. flavus* population was decreased with an increase in radiation intensity. Different studies revealed various findings based on the surviving population and radiation dose level in food samples. In Aquino's study, *A. flavus* sensitivity was much higher than in our research, where a reduction of more than 99% was seen in the 10 Kgy irradiated corn mold population (initial value of  $6 \times 10^6$  cfu/g) (Aquino *et al.*, 2005). In another study, half of the 5 Kgy gamma radiation prevented *A. flavus* sporulation, germination, and growth in corn and feed samples (Markov *et al.*, 2015). Based on one study, the amount of irradiation to destroy total *Aspergillus fungi* in lotus seeds

(with an initial count of 50,000 cfu/g) was found to be 10 KGy (Bhat *et al.*, 2010). In Khorasani's study noted the complete mortality of *A. flavus* spores with 5 KGy gamma rays in pistachio samples (Khorasani *et al.*, 2018). It seems that other factors such as the initial mold population, the water activity (aw) or the relative availability of water in a substance and percentage of the culture medium constituents (Ghanem *et al.*, 2008), and compounds produced by gamma ray (Aquino, 2011) are responsible for the gamma-ray resistance of *A. flavus*.

In our study, it was found that the mold populations in wheat samples could also be affected by irradiation and calcium oxide. Calcium oxide caused not only an increase but a decrease in AFB<sub>1</sub> as well. So that at a higher concentration of calcium oxide, the concentration of AFB<sub>1</sub> increased, which was accompanied by a decline in the *A. flavus* population. However, at the lower calcium oxide content, the concentration of AFB<sub>1</sub> declined, especially in the non-irradiated sample. It appears that the 1% increase in calcium oxide concentration leads to a change in mold growth from the logarithmic to the stationary phase. This results in a reduced mold population and the production of certain secondary metabolites such as AFB<sub>1</sub> (Jay *et al.*, 2005). Jayashree *et al.* (2000) have reported the importance of calcium-calmodulin (Ca<sup>2+</sup>-Calmodulin) and its role in the phosphorylation/dephosphorylation ratio for aflatoxin production using *Aspergillus parasiticus* (Jayashree *et al.*, 2000). Similar to our finding, a 40% reduction in AFB<sub>1</sub> was reported in 2% calcium oxide-treated corn grains during the heating process. The increased calcium oxide concentration did not significantly reduce the toxin and even led to undesirable flavor changes in the product (Abbas *et al.*, 1988). Moreno-Pedraza applied 1% calcium oxide in addition to 90 °C heating in corn processing (tortilla production). Compared with the initial concentration of 125 ppb, a 100% reduction in AFB<sub>1</sub> was revealed (Moreno-Pedraza *et al.*, 2015).

In this research, The decomposition of aflatoxin by gamma rays results from the indirect effects of water-released radicals or other radionuclides, which merely attack AFB<sub>1</sub> and reduce its bioactivity at the terminal furan ring (Rustom, 1997). Similar to the findings of this study, the reduction of AFB<sub>1</sub> (with an initial concentration of 37.61 ppb) in wheat grains with an irradiation dose of 8 KGy was approximately 69.3% (Mohamed-Neeven *et al.*, 2015). However, in barley seed, a greater decrease (90%) in AFB<sub>1</sub> (with an initial concentration of 6410 ppb) was detected at a gamma-ray level of 10 KGy (Ghanem *et al.*, 2008). It is noteworthy that the average loss of AFB<sub>1</sub> in our study (with an initial concentration of 8802 ppb) at 5 and 10 KGy was 48.2% and 57.6%, respectively (data not shown), which is close to Markov's findings. In that research, AFB<sub>1</sub> destruction (with an initial concentration of 50 ppb) in feed and corn samples at 5 and 10 KGy was 60% and 85%, respectively (Markov *et al.*, 2015). In another study, 10 KGy gamma rays caused complete degradation of AFB<sub>1</sub> (with a preliminary content of 2597 ppb) in corn grains (Aquino *et al.*, 2005). The reason for the different resistance of AFB<sub>1</sub>, even in similar samples, may be linked to the initial toxin concentration, the moisture content, the fat and protein content, and the variety of products. In a study, during radiation, because of free radical formation, degradation of AFB<sub>1</sub>, and their interactions, five compounds were produced (Liu *et al.*, 2016).

In our findings, CaO has been shown to influence AFB<sub>2</sub> loss. But controversial papers have been published on the role of calcium in the production of aflatoxins. Although the insignificant role of calcium in aflatoxin production has been reported (Rao *et al.*, 1999), Maggon found that calcium deficiency caused a reduction in aflatoxin production (Maggon *et al.*, 1977). The reason for these differences can be related to the type of mold, the culture medium, and growth conditions (Jay *et al.*, 2005). Based on our results, it was also determined that by increasing the irradiation rate, a decrease in AFB<sub>2</sub> values occurred which were lower than

Aquino's results (Aquino *et al.*, 2005) where the intensity of 10 KGy resulted in the complete degradation of AFB<sub>2</sub> (with an initial concentration of 571.1ppb) in corn specimens.

In this research, the role of calcium oxide in reducing the applied radiation intensity is important, as there has been a marked increase in the destruction of AFB<sub>2</sub> in the presence of CaO at a constant radiation dose. There was even more destruction along with an increase in radiation intensity. It seems that the role of calcium in increasing water activity has increased the effect of gamma radiation in AFB<sub>2</sub>. Aquino *et al.* (2005) reported an increase in aw that led to an increase in the rate of degradation of AFB<sub>2</sub> toxins by gamma rays. In another study, the 2% concentration of calcium oxide (calcium hydroxide solution) and heat treatment in maize processing resulted in a 28% loss of AFB<sub>2</sub> (Abbas *et al.*, 1988). The results of this study showed that, despite a significant reduction of the AFB<sub>1</sub> and AFB<sub>2</sub> by calcium oxide and radiation, due to the high initial concentration of toxins, the remaining toxins were much higher than the European Union's standard (maximum limits for AFB<sub>1</sub> and the total aflatoxins 2 ppb and 4 ppb respectively) (EU, 2006).

### Conclusion

Generally, irradiation inhibited the growth of *A. flavus*, but no synergistic effect between irradiation and calcium oxide was observed. Calcium oxide led to a remarkable inhibition of aflatoxin production at 0.5%, which had a more inhibitory effect on the production of AFB<sub>1</sub> compared to AFB<sub>2</sub>. Unlike the variable effects of calcium oxide concentrations, the effect of irradiation on reduction of the mold population was rather pronounced, so that increasing the dose intensity resulted in a reduction of *A. flavus* colonies and degradation of the majority of AFB<sub>1</sub> and AFB<sub>2</sub> toxins. In conclusion, based on the standard radiation dose limit of 10 KGy for cereals, it is recommended that wheat grains be treated with 0.5% calcium oxide before storage and 10 KGy after storage, in combination, to

achieve the maximum inhibitory effect on *A. flavus* and its aflatoxins.

### Acknowledgments

The authors are grateful to Islamic Azad University, Azadshahr Branch, Iran for providing raw materials, facilities, and laboratory space. This study is a part of an MSc. thesis and did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

**Conflicts of interest:** The authors state that there is no conflict of interest in the publication of this manuscript.

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## کاهش *Aspergillus flavus* و غلظت سموم آفلاتوکسین‌های آن در دانه‌های گندم توسط اکسیدکلسیم و پرتودهی با اشعه گاما

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دریافت: ۴ فروردین ۱۳۹۹؛ پذیرش: ۲۱ آذر ۱۳۹۹

**چکیده:** *Aspergillus flavus* یکی از گونه‌های مهم قارچ‌ها است که می‌تواند سمومی را در زمان انبارداری نامناسب دانه‌های گندم تولید نماید. در این مطالعه مقادیر متفاوت اکسیدکلسیم (صفر، ۰/۵ و ۱ درصد) با نمونه‌های گندم حاوی اسپوره‌های *A. flavus* مخلوط شد. پس از ۲۰ روز، نمونه‌ها در معرض مقادیر متفاوت پرتودهی گاما (صفر، ۵، ۱۰، ۱۵ و ۲۰ کیلوگری) قرار گرفتند. حضور *A. flavus* آفلاتوکسین B<sub>1</sub> (AFB<sub>1</sub>)، آفلاتوکسین B<sub>2</sub> (AFB<sub>2</sub>)، آفلاتوکسین G<sub>1</sub> (AFG<sub>1</sub>) و آفلاتوکسین G<sub>2</sub> (AFG<sub>2</sub>) در نمونه‌ها مورد ارزیابی قرار گرفت. نتایج بیانگر اثرات معنی‌دار اکسیدکلسیم، پرتودهی و برهم‌کنش آن‌ها بر *A. flavus*، سم AFB<sub>1</sub> و سم AFB<sub>2</sub> بود. در این پژوهش، سموم دیگری از قبیل AFG<sub>1</sub> و AFG<sub>2</sub> در نمونه‌ها شناسایی نشد. کاهش بیش‌تر سموم AFB<sub>1</sub> و AFB<sub>2</sub> طی همراهی پرتودهی و اکسیدکلسیم ایجاد شد و بیش‌ترین ممانعت‌کنندگی در تولید آفلاتوکسین‌ها در غلظت ۰/۵٪ اکسیدکلسیم به‌دست آمد. براساس حد استاندارد حداکثر ۱۰ KGy برای دانه‌های غلات، می‌توان به‌کارگیری ۰/۵ درصد اکسیدکلسیم و شدت پرتوی ۱۰ KGy برای ذخیره‌سازی دانه‌های گندم جهت کاهش *A. flavus* و سموم آفلاتوکسین AFB<sub>1</sub> و AFB<sub>2</sub> را توصیه نمود.

**واژگان کلیدی:** *Aspergillus flavus*، آفلاتوکسین‌ها، دانه‌های گندم، پرتودهی گاما، اکسیدکلسیم