

Effects of Processing on Fungal and Aflatoxin Contaminations in Rotting *Solanum lycopersicum* L. (Tomato) Varieties

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Abstract

Tomato (*Solanum lycopersicum* L.) is highly susceptible to fungal infection and aflatoxin contamination, both of which pose significant public health concerns. This study evaluated the effects of different processing methods on fungal contamination and aflatoxin levels in rotting tomato varieties obtained from three markets in Ibadan, Nigeria (Bodija, Ojo, and Oja Oba). Fresh tomatoes were subjected to natural and induced rotting and processed using four methods: milling, milling followed by boiling, milling followed by refrigeration, and refrigeration of raw samples. Fungal species were isolated and identified, while aflatoxin (AFB₁, AFB₂, AFG₁, and AFG₂) concentrations were determined using standard microbiological and chromatographic techniques. Processing significantly reduced fungal contamination across the three markets. Fungal loads ranged from 0.25 to 0.90 cfu g⁻¹ in unprocessed tomato samples but decreased to 0.01–0.30 cfu g⁻¹ following processing, particularly in samples subjected to milling combined with refrigeration. Likewise, aflatoxin concentrations declined substantially after processing. For example, AFB₁ in naturally rotting Royal tomatoes from Bodija market decreased from 0.06 µg/kg in raw samples to 0.01 µg/kg after milling and refrigeration, while induced rotting Royal tomatoes from Ojo market decreased from 0.05 µg/kg to 0.02 µg/kg following the same treatment. Overall, processing methods involving milling combined with refrigeration or boiling were among the most effective treatments for reducing fungal growth and aflatoxin contamination in rotting tomatoes. These findings demonstrate the potential of appropriate processing techniques to improve the microbiological safety of tomato products, although further studies are required to optimise these methods and evaluate their long-term effects.

Keywords: Aflatoxin Levels, Fungal Infections, Food Safety, Human Health, Tomato Processing.

Introduction

Over the past few years, the production of *L* has increased substantially in both cultivated area and total annual output, making tomato an important commodity consumed in both fresh and processed forms (Food and Agriculture Organization of the United Nations,

2024). Tomatoes are also characterised by a high lycopene content, which provides considerable health benefits (Zhang et al., 2024). However, their high moisture content makes them highly susceptible to microbial spoilage (Yadav et al., 2022).

Mature tomatoes contain approximately 94% water and are rich sources of vitamins A, B, and C, with ripe fruits retaining most of their vitamin C in the reduced ascorbic acid form (Ali et al., 2021). Consequently, the high moisture content promotes the rapid growth of bacteria and fungi, thereby accelerating deterioration during storage (Snyder et al., 2024). Postharvest losses resulting from poor storage and handling practices are substantial in developing countries, often ranging from 20% to 50%. Mechanical injuries, including cuts and punctures, further enhance microbial invasion and decay, thereby reducing the economic value of the crop (Chikez et al., 2023). The storage environment of tomatoes can be modified to provide appropriate moisture, aeration, and temperature conditions, while the extent of changes during thermal processing depends on fruit characteristics, initial quality, and processing conditions (Mohan et al., 2023).

Mycotoxins are secondary metabolites produced by fungi and are generally toxic to humans and animals, although they are not necessarily harmful to the fungi that produce them (Khan, 2024).

Tomato production faces significant challenges, including climate variability, pest infestations, water scarcity, and microbial infections, particularly fungal diseases that contribute to postharvest spoilage (Oladipo et al., 2026). Fungal spoilage of tomatoes poses serious public health concerns because exposure to mycotoxins through ingestion or inhalation may result in mycotoxicoses and other adverse health effects (Nan et al., 2022). Despite public health warnings against purchasing deteriorated and damaged tomatoes, locally known as "Esha" among the Yoruba people, their consumption remains common among low-income households, street food vendors, and even affluent families because of prevailing culinary practices in Nigeria (Oduro et al., 2023).

Different microbial species have the capacity to reduce the nutritional quality and marketability of tomatoes through spoilage activities (Abdulsalam et al., 2023). Fungi, in particular, remain major food safety concerns globally because of their ability to colonise food products, cause physical deterioration, and produce toxic secondary metabolites (Saleh et al., 2024).

Some contamination problems can be mitigated through appropriate tomato processing methods and stringent sanitation practices within food-processing facilities (Eslami et al., 2023). Conversely, microbial growth rates decline significantly as storage temperatures decrease, resulting in slower spoilage processes, especially near the freezing point (Oladipo et al., 2026). Aflatoxins are naturally occurring mycotoxins and are regarded as among the most potent naturally occurring carcinogenic compounds (Liu et al., 2024).

Contamination of food and vegetables by aflatoxins has become a major threat to food security, animal health, and public health, particularly in resource-constrained countries (Ashraf et al., 2023). The moisture content of tomatoes is considerably higher than the level required for long-term preservation, creating favourable conditions for rapid bacterial and

fungal proliferation (Thomidis et al., 2023). Despite numerous studies investigating the influence of processing methods on tomato quality, limited information exists regarding the impact of processing on rotting tomatoes (Oduro et al., 2023). Similarly, there is insufficient information concerning the relationship between tomato varieties and the degree of fungal contamination and mycotoxin occurrence (Nan et al., 2022).

The broad objective of this study was to evaluate the effects of different processing methods on fungal contamination and aflatoxin levels in rotting *Solanum lycopersicum* L. varieties obtained from selected markets in Ibadan, Nigeria. The specific objectives were to:

1. Evaluate the effects of different processing methods (milling, boiling, refrigeration, and their combinations) on the fungal load and aflatoxin content of rotting tomato varieties.
2. Compare the fungal contamination and aflatoxin levels of tomato samples obtained from Bodija, Ojo, and Oja Oba markets.
3. Determine the influence of tomato variety (Royal and Scissors) on fungal contamination and aflatoxin occurrence following different processing methods.
4. Compare fungal load and aflatoxin contamination between naturally rotting and artificially induced rotting tomato samples subjected to different processing treatments.

Research hypotheses:

This study was based on the following hypotheses:

1. Processing significantly reduces fungal load and aflatoxin contamination in rotting tomato varieties compared with unprocessed samples.
2. The extent of reduction in fungal load and aflatoxin contamination varies with the processing method employed (milling, boiling, refrigeration, and their combinations).
3. Fungal load and aflatoxin contamination differ among tomato samples obtained from Bodija, Ojo, and Oja Oba markets.
4. Tomato variety (Royal and Scissors) influences the level of fungal contamination and aflatoxin occurrence following processing.
5. Fungal load and aflatoxin contamination differ between naturally rotting and artificially induced rotting tomato samples.

Methodology

Samples Collection

There are two types of fresh and rotting tomatoes, which are locally known as the royal and scissors and a sample of these was gathered in three different markets in the city of Ibadan: Bodija, Ojo, and Oja Oba. The samples were put in four sterilized polythene bags and the information containing the market names, date of collection and varietal name were put on

all the bags. These bags were subsequently transferred in appropriate environmental conditions into the pathology laboratory at the University of Ibadan.

The spoilt samples were taken four days after the deliberate spoilage of the fresh ones. The procedure followed included inoculation of fresh tomatoes with a sterile blade in case of the protocol outlined by (Danaski *et al.*, 2022) and letting tomatoes rot, which took four days before the market rotting samples were taken. A small part of the raw samples was also set aside as a control to later isolate the fungi and aflatoxin, whereas the other samples were processed using different procedures.

Samples Preparation

In this study, four processing techniques were used; milling, milling and boiling, raw samples that were refrigerated and milled samples refrigerated.

Milling: Commercially obtained and experimentally induced tomato samples were first sorted and washed using distilled water. Electric blender was further used to mill the samples. A fragment aseptically collected out of every batch that had been milled was to be assigned to the isolation of fungi as well as evaluation of fungal incidence. The rest of the homogenate was bottled and then tested on the content of aflatoxin.

Milling and Boiling: The tomato samples were sorted and washed with distilled water as before, milled in an electric blender, and then aseptically parboiled ten minutes at 100°C, checking the temperature with a mercury in glass thermometer. The mixture was left to cool and a fragment was aseptically picked to isolate the fungi and determine their incidence. The rest were put in sterile bottles and were forwarded to aflatoxin analysis.

Refrigeration (raw): Purchased and induced raw rotting samples were washed using distilled water and stored in the three-day freeze at 4°C. A portion of the refrigerated product was isolated and assessed fungal incidence and isolated as a fragment in the refrigerated product and put in sterile polyethylene bags to analyze aflatoxin.

Refrigerated (milled): Raw rotting samples were milled using an electric blender after washing using distilled water. The homogenate was immediately milled and then transferred to a sterile bottle, with a lid, and stored in a refrigerator at 4°C, and left there three days. A portion of this refrigerated mixture was sampled to isolate fungi and determine the incidence and the rest was put in a sterile polyethylene bag to be used in aflatoxin assessment.

Isolation of Fungi

PDA was aseptically prepared and poured into petri dishes, and streptomycin was added to them. A sterile blade was used to cut thin sections (3 mm in diameter) of necrotic tomato tissue and place them on the streptomycin-supplemented PDA to prevent the growth of bacteria (Momoh *et al.*; 2020). The dishes were cultured at 27 °C within a period of five days. Later sub-cultures were transferred to PDA slants to obtain pure fungal isolates.

Identification of Fungal Isolates

Fungal isolates obtained from the slant were identified based on their morphology such as colony growth pattern, conidial morphology and pigmentation by slide culture techniques (Lin *et al*; 2023). A small portion of the aerial mycelia from the plated culture was picked using a sterile inoculating needle and was inoculated on a slide containing a fraction of a prepared solidified potato dextrose agar and incubated for 48 h, after which it was viewed under the light microscope first with low resolution objective of x10 and then with high resolution objective of x40 to detect spore, hyphae and other special structures present according to the methods described by (Lucking *et al*; 2020)

i. Extraction and Aflatoxin Analysis

Five gram of the samples were weighed into a conical flask and 2.5 ml of distilled water and 25 ml of chloroform was added. The flask was corked and shaken in a shaker for 30 minutes after which the solution obtained was filtered using a Whatman No. 1 filter paper. 10 ml of each extract or filtrate was collected and evaporated to dryness to a volume of 5 ml on a hot water bath.

ii. Detection of Aflatoxin

One ml of chloroform and 0.2 ml of the reconstituted extract was spotted on a precoated plate along with aflatoxin standard of known concentration. The spotted plate was developed in an equilibrated tank containing chloroform: acetone (9:1 v/v). The developed TLC plate was air dried at ambient temperature ($28 \pm 2^\circ\text{C}$) and aflatoxins were detected under UV light at wavelength of 360 nm. A colour change from blue to yellow upon exposure to aqueous sulphuric acid (50:50 v/v) confirmed the presence of aflatoxin

iii. Quantification of Aflatoxin

Prepared plates of 0.5 mm thick were employed for quantification. 0.8 ml of stored extract above aflatoxin extraction was applied to the plate as band. The preparative plates were developed in an equilibrated tank as in extraction. When the solvent front had risen to about $\frac{3}{4}$ of the total length of the plate, the plate was taken out of the tank and examined under UV light. Once area containing toxin of interest was located after UV light examination, it was scrapped off, elute with chloroform and filter using Whatman No. 1 filter paper. The extract was then evaporated to dryness over a hot water bath and reconstituted with 3ml chloroform. The 3 ml reconstituted solution and aflatoxin standard of 20 µg/ml concentration was used to read absorbance or optical density on an ultraviolet Spectrophotometer at a wavelength of 360 nm. Aflatoxin concentration in µg/kg was calculated using the formula:

$$\frac{\text{Absorbance of sample} \times \text{conc. of standard} \times \text{dil. Factor}}{\text{Absorbance of standard}}$$

The aflatoxin analysis was carried out using an established thin-layer chromatography (TLC) procedure for comparative determination of aflatoxin concentrations among treatments.

Statistical Analysis

Each treatment, market, and tomato variety combination was analysed in triplicate ($n = 3$). The obtained data were subjected to analysis of variance (ANOVA) using SAS (Version 9.6). Means were separated using Duncan's Multiple Range Test (DMRT) at a significance level of $P \leq 0.05$.

Biosafety and Ethical Considerations

This study involved laboratory analyses of tomato samples for fungal isolation and aflatoxin determination. No human participants, animals, or clinical specimens were involved; therefore, formal ethical approval was not required. All laboratory procedures were conducted in accordance with standard laboratory safety and biosafety practices.

Findings and Results

The study revealed thirteen fungi present in the rotting tomato varieties procured from the three markets and they include; *Fusarium oxysporum*, *Fusarium compactum*, *Aspergillus terreus*, *Aspergillus flavus*, *Aspergillus ochraceus*, *Aspergillus parasiticus*, *Aspergillus fumigatus*, *Aspergillus niger*, *Penicillium oxalicum*, *Penicillium citrinum*, *Penicillium chrysogenum*, *Penicillium ovalium*, *Saccharomyces cerevesiae*.

Table 1 outlines the effect of different processing methods on the incidence of mycotic growth and the biomass in naturally and experimentally induced rotting tomato varieties. The biomass of mycotic organisms in naturally decayed samples of both types reduced after processing in all samples of the market (Bodija, Ojo, and Oja Oba). The results showed a statistically significant reduction of fungal load on processed samples compared to their unprocessed counterparts (royal and scissors) collected in the three markets. Among all the methods of processing tested, the milled and refrigerated samples showed the least fungal biomass. All in all, the data show that the various processing regimes significantly reduce the mycotic load in rotting tomatoes.

Table 1: Effects of Processing on Fungal Load (cfug⁻¹) of tomato samples from three selected markets

S/N	Treatment	Bodija	Ojo	Oja oba
1	NR _w (R)	0.90a	0.65a	0.75a
2	NR _w and RF (R)	0.5cd	0.50f	0.55c
3	NM (R)	0.50cd	0.25ef	0.65b
4	NM and B (R)	0.60bc	0.30de	0.30ef
5	NM and RF (R)	0.30e	0.20f	0.10h
6	NR _w (S)	0.70ab	0.45b	0.60bc
7	NR _w and RF (S)	0.75b	0.10g	0.35e
8	NM (S)	0.60bc	0.30de	0.35e
9	NM and B (S)	0.50cd	0.40bc	0.20g
10	NM and RF (S)	0.10f	0.20f	0.10h

S/N	Treatment	Bodija	Ojo	Oja oba
11	IR _w (R)	0.25ef	0.70a	0.45d
12	IR _w and RF (R)	0.10f	0.20f	0.20g
13	IM (R)	0.10f	0.30de	0.25fg
14	IM and B (R)	0.2ef	0.35cd	0.20g
15	IM and RF (R)	0.10f	0.30de	0.10h
16	IR _w (S)	0.35de	0.30de	0.25fg
17	IR _w and RF (S)	0.10f	0.10g	0.20g
18	IM (S)	0.10f	0.20f	0.20g
19	IM and B (S)	0.10f	0.10g	0.20g
20	IM and RF (S)	0.01f	0.10g	0.10h

Means with different letters in each column are significantly different ($P \leq 0.05$).

Source: Author's Laboratory data, 2026

NR_w(R)= NATURAL RAW (ROYAL), NR_w and RF (R)= NATURAL RAW AND REFRIGERATED (ROYAL), NM (R)= NATURAL MILLED (ROYAL), NM and B (R)= NATURAL MILLED AND BOILED (ROYAL), NM and RF (R)= NATURAL MILLED AND REFRIGERATED (ROYAL)

NR_w (S)= NATURAL RAW (SCISSORS), NR_w and RF (S)= NATURAL RAW and REFRIGERATED (SCISSORS), NM (S)= NATURAL MILLED (SCISSORS), NM and B (S)= NATURAL MILLED and BOILED (SCISSORS), NM and RF (S)= NATURAL MILLED and REFRIGERATED (SCISSORS).

IR_w (S)= INDUCED RAW (SCISSORS), IR_w and RF (S)= INDUCED RAW AND REFRIGERATED (SCISSORS), IM (S)= INDUCED MILLED (SCISSORS), IM and B (S)= INDUCED MILLED and BOILED (SCISSORS), IM and RF (S)= INDUCED MILLED and REFRIGERATED (SCISSORS)

Table 2 presents results of processing effects on the aflatoxin content of rotting tomatoes varieties obtained at Bodija market. It was determined that samples contained less aflatoxin after processing. The samples of rotting tomatoes were found to have aflatoxin types (AFB₁, AFB₂, AFG₁ and AFG₂) except some which did not find it. The aflatoxin contaminations of natural and induced rotting tomato samples (royal and scissors variety) decreased post-processing.

The aflatoxin levels were greatly decreasing in the processed and the unprocessed samples of rotting tomato (royal and scissors varieties). Processing methods significantly ($P \leq 0.05$) influenced aflatoxin concentrations in the rotting tomato varieties, as indicated by the different superscript letter groupings across treatments. Overall, processing reduced aflatoxin levels, although the extent of reduction varied among the different processing methods.

Table 2: Effects of Processing on Aflatoxin Content (μgkg^{-1}) of Rotting Tomato Varieties obtained from Bodija Market.

S/N	Treatment	AFB ₁	AFB ₂	AFG ₁	AFG ₂
1	NR _w (R)	0.06ab	0.07ab	0.07a	0.08a
2	NR _w and RF(R)	0.06ab	0.05cde	0.07ab	0.07ab
3	NM (R)	0.04d	0.04de	0.05de	0.06cd
4	NM and B (R)	0.04cd	0.05cd	0.05cd	0.05d
5	NM and RF (R)	0.01ef	Nd	0.00h	0.02g
6	NR _w (S)	0.07a	0.07a	0.06bc	0.07ab
7	NR _w and RF (S)	0.05bc	0.04e	0.04ef	0.06d
8	NM (S)	0.04cd	0.05cd	0.05cd	0.07bc
9	NM and B (S)	0.04d	0.06bc	0.05d	0.06d
10	NM and RF (S)	0.02e	0.02f	0.03f	0.04e
11	IR _w (R)	0.04a	0.02f	0.04f	0.04e
12	IR _w and RF (R)	0.01ef	Nd	0.02g	0.04e
13	IM (R)	0.01ef	Nd	0.00h	0.00h
14	IM and B (R)	0.01ef	Nd	0.00h	0.02g
15	IM and RF (R)	0.00f	0.00g	0.00h	0.00h
16	IR _w (S)	0.04a	0.02f	0.02g	0.03f
17	IR _w and RF (S)	0.01ef	Nd	0.02g	0.01h
18	IM (S)	0.01ef	Nd	0.00h	0.00h
19	IM and B (S)	0.01ef	Nd	0.00h	0.00h
20	IM and RF (S)	0.01ef	Nd	0.00h	0.00h

Means with different letters in each column are significantly different. ($P \leq 0.05$).

Source: Author's Laboratory data, 2026

Table 3 shows how processing affects the aflatoxin content of the rotting tomato varieties obtained in Ojo market. The aflatoxin levels of the samples reduced after processing. The four predominant types of aflatoxins AFB₁, AFB₂, AFG₁, and AFG₂ were found in both natural and induced samples of the rotting tomato varieties, and a small fraction of samples showed no detectable concentration. The level of contamination in the natural and induced samples of Royal and Scissors varieties reduced after processing, and in some instances the aflatoxins were not detected after the processing. It was found that there was a strong decrease in the levels of aflatoxins in processed and unprocessed samples of both the Royal and Scissors varieties, in the natural and induced groups. After processing, refrigerated and milled samples had the lowest levels of aflatoxins in a number of samples.

Table 3: Effect of Processing on Aflatoxin Content (μgkg^{-1}) of Rotting Tomatoes Varieties obtained from Ojo Market.

S/N	Treatment	AFB ₁	AFB ₂	AFG ₁	AFG ₂
1	NR _w (R)	0.04c	0.05c	0.06ab	0.07a
2	NR _w and RF(R)	0.00i	Nd	0.00h	Nd

S/N	Treatment	AFB ₁	AFB ₂	AFG ₁	AFG ₂
3	NM (R)	0.02f	0.02fg	0.03def	0.04d
4	NM and B (R)	0.02f	0.03ef	0.03def	0.05cd
5	NM and RF (R)	0.04cd	0.05cd	0.06a	0.04d
6	NR _w (S)	0.06a	0.08a	0.05bc	0.06bc
7	NR _w and RF (S)	0.00i	Nd	0.00h	Nd
8	NM (S)	0.01gh	Nd	0.02gf	0.03ef
9	NM and B (S)	0.02f	0.02fg	0.03de	0.04d
10	NM and RF (S)	0.01h	0.02fg	0.02efg	0.04de
11	IR _w (R)	0.05b	0.06b	0.05bc	0.06ab
12	IR _w and RF (R)	0.00i	Nd	0.00h	Nd
13	IM (R)	0.03e	0.01g	0.03ef	0.04de
14	IM and B (R)	0.03e	0.04cd	0.03de	0.04de
15	IM and RF (R)	0.02fg	0.02fg	0.03ef	0.02f
16	IR _w (S)	0.05b	0.07ab	0.05bc	0.06ab
17	IR _w and RF (S)	0.00i	Nd	0.00h	Nd
18	IM (S)	0.02f	Nd	0.01g	0.03ef
19	IM and B (S)	0.03d	0.04de	0.04cd	0.06bc
20	IM and RF (S)	0.01h	0.02fg	0.03ef	0.06bc

Means with different letters in each column are significantly different. ($P \leq 0.05$).

Source: Author's Laboratory data, 2026

Table 4 presents the effects of different processing methods on the aflatoxin content (AFB₁, AFB₂, AFG₁, and AFG₂) of naturally and induced rotted Royal and Scissors tomato varieties obtained from Oja Oba Market. The results show that processing generally led to a reduction in aflatoxin concentrations across all samples. All four aflatoxins were detected in most unprocessed rotting tomato samples, although several processed samples recorded non-detectable (Nd) levels, particularly for AFB₁, AFB₂, and AFG₂.

The presence of different superscript letters (a–e) across treatments within each aflatoxin column indicates that there are statistically significant differences ($P \leq 0.05$) among specific processing treatments. This means that while all processing methods contributed to aflatoxin reduction, the extent of reduction was not uniform across treatments, and some processing methods differed significantly from others in their effectiveness.

In naturally rotted Royal tomatoes, for example, processing reduced AFB₂ from 0.03 $\mu\text{g kg}^{-1}$ in the raw sample to 0.01–0.02 $\mu\text{g kg}^{-1}$ depending on the treatment, while AFG₁ decreased from 0.04 $\mu\text{g kg}^{-1}$ to as low as 0.01 $\mu\text{g kg}^{-1}$. Similar patterns were observed in the Scissors variety, where processing reduced AFG₁ from 0.04 $\mu\text{g kg}^{-1}$ to 0.01 $\mu\text{g kg}^{-1}$ in some treatments. In several cases, AFG₂ was completely undetectable after processing.

Induced rotted samples showed a similar trend, with boiling and roasting treatments producing non-detectable levels of AFB₁, AFB₂, and AFG₂ in some cases, while AFG₁ persisted at low concentrations (0.01 $\mu\text{g kg}^{-1}$). Overall, processing significantly reduced aflatoxin contamination; however, the effectiveness varied among treatments, as reflected in the significant differences indicated by the letter groupings.

Table 4: Effects of Processing on Aflatoxin Content (μgkg^{-1}) of Rotting Tomatoes Varieties obtained from Oja Oba Market.

S/N	Treatment	AFB ₁	AFB ₂	AFG ₁	AFG ₂
1	NR _w (R)	0.02a	0.03a	0.04a	0.03b
2	NR _w and RF(R)	0.02a	0.02c	0.01e	Nd
3	NM (R)	0.02a	0.02c	0.03c	0.02bc
4	NM and B (R)	0.01c	0.01d	0.03c	0.01d
5	NM and RF (R)	0.01c	0.01d	0.01e	Nd
6	NR _w (S)	0.02a	0.03b	0.04b	0.05a
7	NR _w and RF (S)	0.01c	0.01d	0.01e	Nd
8	NM (S)	0.01c	0.02c	0.03c	0.02c
9	NM and B (S)	0.01c	0.01d	0.02d	0.01d
10	NM and RF (S)	0.01c	0.01d	0.01e	Nd
11	IR _w (R)	0.02ab	0.02c	0.03c	0.02c
12	IR _w and RF (R)	0.01c	0.01d	0.01e	Nd
13	IM (R)	0.01c	0.01d	0.02d	0.01d
14	IM and B (R)	Nd	Nd	0.01e	Nd
15	IM and RF (R)	Nd	Nd	0.01e	Nd
16	IR _w (S)	0.01c	0.02c	0.02d	0.01d
17	IR _w and RF (S)	0.01c	0.01d	0.01e	Nd
18	IM (S)	0.01c	0.01d	0.02d	0.01d
19	IM and B (S)	Nd	Nd	0.01e	Nd
20	IM and RF (S)	Nd	Nd	0.01e	Nd

Means with different letters in each column are significantly different. ($P \leq 0.05$).

Source: Author's Laboratory data, 2026

Table 5 shows the processing effects on fungal load in natural and induced rotting tomatoes. There was a significant difference between the natural and induced samples in all the markets analyzed. The naturally rotting samples had the best fungal load, and the induced samples had the worst.

Table 5: Effects of Processing in Fungal Load (cfug^{-1}) in the Natural and Induced Rotting Tomatoes.

Fruit Condition	Bodija	Ojo	Oja Oba
Natural	0.55a	0.40a	0.31a
Induced	0.16b	0.22b	0.27b

Means with different letters in each column are significantly different. ($P \leq 0.05$).

Source: Author's Laboratory data, 2026

Table 6 illustrates the effect of processing on fungal load of tomato varieties that were rotted in different markets. Although no significant difference was observed between samples of Bodija market in terms of fungal load, there was a significant difference in the

royal and scissors types in the samples emanating out of the Ojo and Oja Oba markets. The most fungal load was seen in the royal type but the least in the scissors type.

Table 6: Effects of Processing on Fungal Load (cfug⁻¹) of the Tomato Varieties.

Varieties	Bodija	Ojo	Oja Oba
Royal	0.35a	0.36a	0.35a
Scissors	0.37a	0.26b	0.23b

Source: Author's Laboratory data, 2026

Table 7 describes the processing effects on the aflatoxin contamination in rotting tomato varieties in Bodija market. There were no significant differences in the level of AFB₁, AFB₂ and AFG₁ in the royal and scissors varieties, but there was a major difference in the levels of AFG₂. The royal type always had the largest AFG₂ contamination.

Table 7: Effects of Processing on Aflatoxin Contamination (µgkg⁻¹) of Tomato Varieties procured in Bodija Market

Varieties	AFB ₁	AFB ₂	AFG ₁	AFG ₂
Royal	0.01a	0.03a	0.03a	0.04a
Scissors	0.01a	0.03a	0.02a	0.03b

Source: Author's Laboratory data, 2026

Table 8 shows how processing influences the aflatoxin contamination of tomato varieties acquired in Ojo market. The AFB₁ content did not show any statistically significant difference between the varieties but the AFB₂, AFG₁ and AFG₂ contents showed significant differences among the two samples. The Royal type had the highest concentrations when compared to the Scissors type.

Table 8: Effects of Processing on Aflatoxin Contamination (µgkg⁻¹) of Tomato Varieties procured in Ojo Market

Varieties	AFB ₁	AFB ₂	AFG ₁	AFG ₂
Royal	0.03a	0.02a	0.03a	0.03a
Scissors	0.03a	0.01b	0.02b	0.02b

Source: Author's Laboratory data, 2026

Table 9 shows the impact of processing on aflatoxin contamination of tomato varieties obtained in the Oja Oba market. The content-reduction of AFB₁ was not significantly different between the Royal and Scissors varieties but the content-reduction of AFB₂, AFG₁, and AFG₂ was significantly higher in the Royal variety compared to the Scissors one. Therefore, the Royal variety showed a greater aflatoxin contamination after processing.

Table 9: Effects of Processing on Aflatoxin Contamination (μgkg^{-1}) of Tomato Varieties procured in Oja Oba Market.

Varieties	AFB ₁	AFB ₂	AFG ₁	AFG ₂
Royal	0.04a	0.01a	0.01a	0.02a
Scissors	0.04a	0.00b	0.00b	0.01b

Source: Author's Laboratory data, 2026

Table 10 is a comparison of the levels of aflatoxins in naturally and induced-rotting tomatoes after processing at the Bodija market. A major decrease of the aflatoxin levels was detected in the induced-rotting samples, and the naturally rotting samples had more AFB₁, AFB₂, AFG₁, and AFG₂ levels after processing.

Table 10: Comparison between Aflatoxin contents (μgkg^{-1}) of Natural and Induced Rotting Tomatoes after Processing (Bodija Market).

Fruit Condition	AFB ₁	AFB ₂	AFG ₁	AFG ₂
Natural	0.01a	0.04a	0.05a	0.06a
Induced	0.00b	0.01b	0.01b	0.01b

Source: Author's Laboratory data, 2026

Table 11 is a comparison of aflatoxin levels in natural and induced-rotting tomatoes after processing in the Ojo market. There was no noticeable reduction in the contents of AFB₂ and AFG₁ in the induced-rotting tomatoes in comparison to the natural tomatoes; however, it was clear that the contents of AFB₁ and AFG₂ of the induced-rotting tomatoes were significantly reduced in comparison to the natural tomatoes.

Table 11: Comparison between Aflatoxin contents (μgkg^{-1}) of Natural and Induced Rotting Tomatoes after Processing (Ojo Market).

Fruit Condition	AFB ₁	AFB ₂	AFG ₁	AFG ₂
Natural	0.05a	0.02a	0.03a	0.03a
Induced	0.01b	0.02a	0.03a	0.02b

Source: Author's Laboratory data, 2026

Table 12 is a comparison between aflatoxin levels in natural and induced rotting tomatoes after processing at the Oja Oba market. There were no significant differences between the AFB₁ contents of the induced-rotting samples and the naturally rotting tomatoes, but the AFB₂, AFG₁ and AFG₂ contents of the induced-rotting tomatoes were significantly reduced. In this regard, naturally rotting tomatoes had the highest contamination of aflatoxins compared with the other samples collected in Oja Oba.

Table 12: Comparison between Aflatoxin contents (μgkg^{-1}) of Natural and Induced Rotting Tomatoes after Processing (Oja Oba Market).

Fruit Condition	AFB ₁	AFB ₂	AFG ₁	AFG ₂
Natural	0.04a	0.02a	0.01a	0.02a
Induced	0.04a	0.01b	0.00b	0.01b

Source: Author's Laboratory data, 2026

Table 13 shows the prevalence of fungal isolates by tomato varieties that were rotting. The statistics reveal that there is a statistically significant difference in the prevalence of some fungal species, *A. terreus*, *A. flavus*, *A. fumigatus*, and *P. oxalicum*, between the Royal and Scissors tomato cultivars. On the other hand, the other fungi found in processed and unprocessed samples did not show any significant differences.

Table 13: fungal occurrence in variety of rotting tomatoes.

Varieties	<i>A. terreus</i>	<i>A. flavus</i>	<i>A. ochraceous</i>	<i>A. parasiticus</i>	<i>A. fumigatus</i>	<i>P. oxalicum</i>	<i>A. niger</i>	<i>Saccharomyces cerevisiae</i>	<i>Fusarium Compactum</i>	<i>P. citrinum</i>	<i>P. chrysogenum</i>	<i>P. ovalium</i>	<i>F. oxysporum</i>
Royal	1.0a	0.67a	0.00a	0.007a	0.004a	0.007a	0.02a	0.03a	0.03a	0.03a	0.03a	0.03a	0.00a
Scissors	0.9b	0.4b	0.00a	0.00a	0.002b	0.00b	0.13a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a

Means with different letters in each column are significantly different ($p \leq 0.05$).

Source: Author's Laboratory data, 2026

Table 14 illustrates fungal occurrence of rotting tomatoes varieties that are obtained in different markets. The analysis does not show a statistically significant difference in the fungal occurrence of processed and unprocessed tomatoes in Bodija, Ojo and Oja Oba

Table 14: fungal occurrence in rotting tomato varieties obtained from different markets.

Market	<i>A. terreus</i>	<i>A. flavus</i>	<i>A. ochraceus</i>	<i>A. parasiticus</i>	<i>A. fumigatus</i>	<i>P. oxalicum</i>	<i>A. niger</i>	<i>Saccharomyces cerevisiae</i>	<i>Fusarium compactum</i>	<i>P. citrinum</i>	<i>P. chrysogenum</i>	<i>P. ovalium</i>	<i>F. oxysporum</i>
Bodija	1.0a	0.55a	0.00a	0.10a	0.25a	0.10a	0.10a	0.05a	0.00a	0.00a	0.00a	0.00a	0.00a

Market	<i>A. terreus</i>	<i>A. flavus</i>	<i>A. ochraceus</i>	<i>A. parasiticus</i>	<i>A. fumigatus</i>	<i>P. oxalicum</i>	<i>A. niger</i>	<i>Saccharomyces cerevisiae</i>	<i>Fusarium compactum</i>	<i>P. citrinum</i>	<i>P. chrysogenum</i>	<i>P. ovale</i>	<i>F. oxysporum</i>
Ojo	0.95ab	0.45a	0.0a	0.00a	0.30a	0.0ob	0.15a	0.00a	0.05a	0.05a	0.05a	0.05a	0.00a
Oja Obaba	0.9b	0.60a	0.0a	0.00a	0.35a	0.0ob	0.25a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a

Means with different letters in each column are significantly different ($p \leq 0.05$).

Source: Author's Laboratory data, 2026

Figure 1 shows the total fungal load in rotting tomatoes from the three markets. Bodija market had the highest fungal load as compared to ojo market and oja oba. Ojo market had the lowest fungal load.

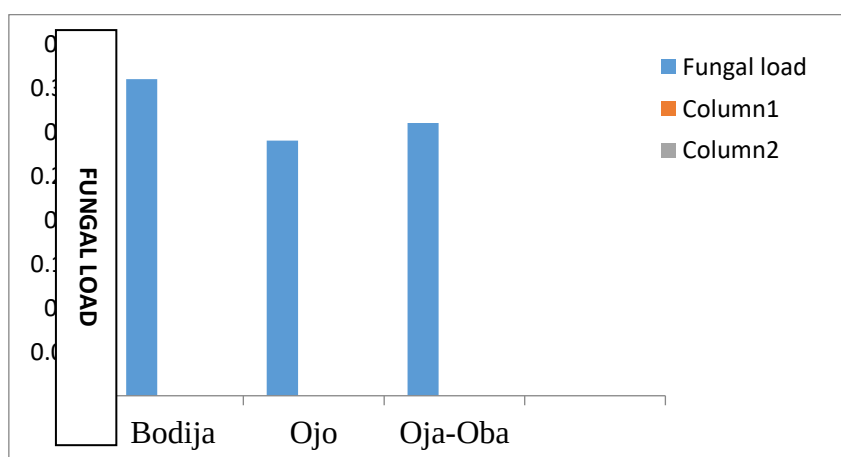


Figure 1: Total fungal load in rotting tomatoes from the three markets.

Source: Author's Laboratory data, 2026

Discussion

The various forms of aflatoxin that have been identified in tomato varieties that are rotting, support the report by Okechukwu *et al.*, (2024) and Tiwari *et al.*, (2023) and whose formation depends on the temperature, water activity and oxygen of the storage facility. Nizamlioglu (2022) also stated fungi that are related to tomatoes and this confirms the current research although there are minor differences that might be caused by variations in the environment in which tomatoes were kept before ultimate procurement.

The sample content of aflatoxins was observed to decline in majority of the samples post processing, which is comparatively equivalent to the report by Marshall *et al.*, (2020). This

could be attributed to the factors of dilution; in a number of samples, the most reduction was recorded in the milled and refrigerated samples, which could be attributed to reduction caused by milling as reported by Adebo *et al.*, (2021) as well as refrigeration, which is commonly known to inactivate the growth of fungi and its forms.

The contamination with fungi and aflatoxins was observed to decrease considerably in certain raw and refrigerated samples at certain times, possibly as a result of storing time, efficient packaging as well as the efficacy of the freezer employed. This is in line with Nan *et al.*, (2022) reports. However, there was no substantial decrease at other times and this could be as a result of fact that refrigeration only inactivates the fungal activities, but at room temperature, may be reactivated and this justifies the report by Liu *et al.*, (2020).

The lack of milling could also have helped to reduce the fungal aflatoxin contamination in selected rotting samples; this observation has been supported by Kinyoro and Kaale (2024) and Afsah-Hejri *et al.*, (2020). Moreover, the high fungal load that has been realized in natural tomato varieties undergoing rot may be credited to the fact that damaged and rotting tomatoes are exposed to unhygienic market conditions, besides the extended storage period that aids in contamination, as is the case with the studies of Nan *et al.*, (2022).

The high titres of aflatoxins in most of the samples of the royal variety can be related to inherent structural factors or storage conditions, results that align with Jallow *et al.*, (2021). Also, the recorded increment may be due to transit environment of the type and shipment time a hypothesis that follows Liu *et al.*, (2020). The lack of some classes of aflatoxins in some of the samples perhaps indicates that not all fungal species are endowed with the genetic machinery required to produce aflatoxins, which validates the findings made by Alizadeh *et al.*, (2022). Also, the low level of aflatoxin in the raw material could have been reduced even more by the process of further processing.

The fact that fungal and aflatoxin contamination can persist despite processing is highlighted in Afsah-Hejri *et al.*, (2020), which shows that these interventions do not fully eliminate these hazards. Additionally, the relatively low percentage of fungal and aflatoxin contamination in rotting tomato samples cannot be ignored as they may trigger a range of disease conditions due to cumulative effects, and this is supported by WHO (2023).

Conclusion

The current research has shown that the nature of processing applied on rotting tomatoes has a strong impact on the reduction of fungal load and aflatoxin contamination. Specifically, milling coupled with boiling or refrigerated storage has been identified to be effective in inhibiting the growth of fungi and aflatoxins in tomatoes, thus improving their safety to human consumption. These results of the decrease in microbial contamination and aflatoxins under the given processing regimes indicate that these techniques might be used as effective interventions to reduce the risk of the hazards related to the consumption of rotting tomatoes. However, it is crucial to note that despite the mitigation advantages that are brought by processing, consumption of rotting tomatoes remains a possible health

risk, particularly because of the existence of mycotoxins. Therefore, processing may help to reduce the level of contamination, but it, in reality, does not eliminate the risk completely.

Recommendations

The health risks presented by the consumption of rotting tomatoes justify a precautionary position, whereby consumers are highly encouraged to avoid the regular consumption of tomatoes with apparent signs of spoilage. When consumption becomes inevitable, preference must be given to processed tomato products which have been subjected to interventions which include milling followed by boiling, or milling followed by refrigeration. It has been empirically shown that the modalities of processing significantly reduce fungal growth and aflatoxin contamination.

There should be increased campaigns to educate the masses of people about the dangers of eating low quality tomatoes, especially in the informal market, and the importance of careful postharvesting and of effective processing methods. Greater awareness programs should be involved in developing a wider perspective of these dangers among the general population. Further research is justified to examine other processing options that can further reduce contamination in spoilt tomatoes. In addition, studies are needed to determine the longitudinal effects of these methods on tomato quality indices and general safety, therefore, forming best-practice principles in the food sector.

Conflicts of Interest

The authors declare no conflicts of interest.

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References

- Abdulsalam, R. A., Ijabadeniyi, O. A., Cason, E. D., & Sabiu, S. (2023). Characterization of microbial diversity of two tomato cultivars through targeted next-generation sequencing 16S rRNA and ITS techniques. *Microorganisms*, 11(9), 2337. <https://doi.org/10.3390/microorganisms11092337>
- Adebo, O. A., Molelekoa, T. B. J., Makhuvele, R., Adebisi, J. A., Oyediji, A. B., Gbashi, S., Adefisoye, M. A., Ogundele, O. M., & Njobeh, P. B. (2021). Novel non-thermal food processing techniques for mycotoxin reduction. *International Journal of Food Science & Technology*, 56(1), 13–27. <https://doi.org/10.1111/ijfs.14734>
- Afsah-Hejri, L., Hajeb, P., & Ehsani, R. J. (2020). Application of ozone for degradation of mycotoxins in food: A review. *Comprehensive Reviews in Food Science and Food Safety*, 19(4), 1777–1808. <https://doi.org/10.1111/1541-4337.12594>
- Ali, M. Y., Sina, A. A. I., Khandker, S. S., Neesa, L., Tanvir, E. M., Kabir, A., Khalil, M. I., & Gan, S. H. (2021). Nutritional composition and bioactive compounds in tomatoes and their impact on human health and disease: A review. *Foods*, 10(1), 45. <https://doi.org/10.3390/foods10010045>

- Alizadeh, A., Shakeri, G., Marhamati, M., & Afshari, A. (2022). A systematic review on the diversity and importance of mycotoxins in tomato and derived products. <https://doi.org/10.1079/cabireviews202217015>
- Ashraf, W., Rehman, A., Rabbani, M., Shaukat, W., & Wang, J. S. (2023). Aflatoxins posing threat to food safety and security in Pakistan: Call for a one health approach. *Food and Chemical Toxicology*, 180, 114006. <https://doi.org/10.1016/j.fct.2023.114006>
- Chikez, H., Maier, D., Olafsson, S., & Sonka, S. (2023). Identifying critical drivers of mango, tomato, and maize postharvest losses in low-income countries and predicting their impact. *Agriculture*, 13(10), 1912. <https://doi.org/10.3390/agriculture13101912>
- Danaski, A. I., Shugaba, A., Milala, M. A., Ndirmbula, J. B., & Gidado, A. (2022). Isolation, identification and pathogenicity study of the microbes causing tomato post-harvest spoilage in Maiduguri metropolis, Nigeria. *Nigerian Journal of Biochemistry and Molecular Biology*, 37(4), 303–313.
- Eslami, E., Abdurrahman, E., Ferrari, G., & Pataro, G. (2023). Enhancing resource efficiency and sustainability in tomato processing: A comprehensive review. *Journal of Cleaner Production*, 425, 138996. <https://doi.org/10.1016/j.jclepro.2023.138996>
- Food and Agriculture Organization of the United Nations. (2024). *FAOSTAT crops and livestock products database*. <https://www.fao.org/faostat/>
- Jallow, A., Xie, H., Tang, X., Qi, Z., & Li, P. (2021). Worldwide aflatoxin contamination of agricultural products and foods: From occurrence to control. *Comprehensive Reviews in Food Science and Food Safety*, 20(3), 2332–2381. <https://doi.org/10.1111/1541-4337.12734>
- Khan, R. (2024). Mycotoxins in food: Occurrence, health implications, and control strategies—A comprehensive review. *Toxicon*, 248, 108038. <https://doi.org/10.1016/j.toxicon.2024.108038>
- Kinyoro, I. S., & Kaale, L. (2024). Technologies to decontaminate aflatoxins in foods: A review. *International Journal of Food Science & Technology*, 59(10), 6783–6796. <https://doi.org/10.1111/ijfs.17435>
- Lin, P., Kook, M. C., Yi, T. H., & Yan, Z. F. (2023). Current fungal taxonomy and developments in the identification system. *Current Microbiology*, 80, 375. <https://doi.org/10.1007/s00284-023-03514-7>
- Liu, Y., Yamdeu, J. H. G., Gong, Y. Y., & Orfila, C. (2020). A review of postharvest approaches to reduce fungal and mycotoxin contamination of foods. <https://doi.org/10.1111/1541-4337.12562>
- Liu, M., Zhang, X., Luan, H., Zhang, Y., Xu, W., Feng, W., & Song, P. (2024). Bioenzymatic detoxification of mycotoxins. *Frontiers in Microbiology*, 15, 1434987. <https://doi.org/10.3389/fmicb.2024.1434987>
- Lücking, R., Aime, M. C., Robbertse, B., et al. (2020). Unambiguous identification of fungi: Where do we stand? *IMA Fungus*, 11, 14. <https://doi.org/10.1186/s43008-020-00033-z>
- Marshall, H., Meneely, J. P., Quinn, B., Zhao, Y., Bourke, P., Gilmore, B. F., Zhang, G., & Elliott, C. T. (2020). Novel decontamination approaches and their potential application for post-harvest aflatoxin control. *Trends in Food Science & Technology*, 106, 489–496. <https://doi.org/10.1016/j.tifs.2020.11.001>
- Mohan, A., Krishnan, R., Arshinder, K., Vandore, J., & Ramanathan, U. (2023). Management of postharvest losses and wastages in the Indian tomato supply chain—A temperature-controlled storage perspective. *Sustainability*, 15(2), 1331. <https://doi.org/10.3390/su15021331>
- Momoh, A. O., Aladeyelu, A. E., & Tuomokeme, D. E. (2020). Isolation and identification of spoilage microorganisms from different varieties of tomatoes. *European Journal of Biotechnology and Bioscience*, 8(5), 47–52.
- Nan, M., Xue, H., & Bi, Y. (2022). Contamination, detection and control of mycotoxins in fruits and vegetables. *Toxins*, 14(5), 309. <https://doi.org/10.3390/toxins14050309>
- Nizamlioglu, N. M. (2022). Relationship between ergosterol and mycotoxins in tomato paste and tomato juice. <https://doi.org/10.1111/jfpp.16937>

- Oduro, L., Allotey, J. A., Akyereko, Y. G., Wireko-Manu, F. D., & Akowuah, J. O. (2023). A comparative study on phytochemical, nutritional and microbial load of fresh and spoiled tomatoes (*Lycopersicon esculentum* L.). *Research on Crops*, 24(4), 727–736. <https://doi.org/10.31830/2348-7542.2023.ROC-11170>
- Okechukwu, V. O., Adelusi, O. A., Kappo, A. P., Njobeh, P. B., & Mamo, M. A. (2024). Aflatoxins: Occurrence, biosynthesis, mechanism of action and effects, conventional/emerging detection techniques. *Food Chemistry*, 436, 137775. <https://doi.org/10.1016/j.foodchem.2023.137775>
- Oladipo, E. K., Oladipo, B., Ojumu, T. V., & Caleb, O. J. (2026). Postharvest losses of tomato: Causes, spoilage mechanisms, and advances in conventional and emerging technologies for preservation. *Food Research International*, 227, 118247. <https://doi.org/10.1016/j.foodres.2025.118247>
- Saleh, I., Zeidan, R., & Abu-Dieyeh, M. (2024). The characteristics, occurrence, and toxicological effects of alternariol: A mycotoxin. *Archives of Toxicology*, 98, 1659–1683. <https://doi.org/10.1007/s00204-024-03743-0>
- Snyder, A. B., Martin, N., & Wiedmann, M. (2024). *Microbial food spoilage: impact, causative agents and control strategies*. *Nature Reviews Microbiology*, 22, 528–542. <https://doi.org/10.1038/s41579-024-01037-x>
- Thomidis, T., Prodromou, I., Paresidou, M., (2023). Effects of temperature and leaf wetness duration on pathogens causing preharvest fruit rots on tomato. *Journal of Plant Pathology*, 105, 1431–1448. <https://doi.org/10.1007/s42161-023-01443-9>
- Tiwari, S., Singh, B. K., & Dubey, N. K. (2023). Aflatoxins in food systems: Recent advances in toxicology, biosynthesis, regulation and mitigation through green nanoformulations. *Journal of the Science of Food and Agriculture*, 103(4), 1621–1630. <https://doi.org/10.1002/jsfa.12265>
- World Health Organization. (2023, October 2). *Mycotoxins*. <https://www.who.int/news-room/fact-sheets/detail/mycotoxins>
- Yadav, S., Barman, K., Chandra Nayaka, S.,. (2022). Edible coating as postharvest management strategy for shelf-life extension of fresh tomato (*Solanum lycopersicum* L.): An overview. *Journal of Food Science*, 87(6), 2297–2321. <https://doi.org/10.1111/1750-3841.16145>
- Zhang, X., Zhou, Q., Qi, Y., Chen, X., Deng, J., Zhang, Y., Li, R., & Fan, J. (2024). The effect of tomato and lycopene on clinical characteristics and molecular markers of UV-induced skin deterioration: A systematic review and meta-analysis of intervention trials. *Critical Reviews in Food Science and Nutrition*, 64(18), 6198–6217. <https://doi.org/10.1080/10408398.2022.2164557>