Development of Optical-based and Imaging Technology Detection, Diagnosis and Prevention of Aflatoxin Contamination on Maize Crop

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ABSTRACT

Aflatoxins are mycotoxins produced naturally by some mold strains, such as Aspergillus flavus and Aspergillus parasiticus. Weather factors, notably moisture levels of more than 18 percent and temperatures of more than 32°C, influence the proliferation of aflatoxin-producing fungus. Aflatoxin pollution is a danger to human and animal healthiness. As a result, there is a pressing need to control aflatoxin, particularly in crops like maize, in countries where aflatoxin susceptibility is high, such as Tanzania. Several aflatoxin management solutions are being developed, however, for them to be effective, accurate identification of fungus or aflatoxins contamination on grain surfaces is required. While the majority of the known solutions include growing and identifying the fungus responsible or using Higher-Performance Liquid Chromatography (HPCL), Thin Layer Chromatography (TLC), and Enzyme-Linked Immunosorbent Assays (ELISA) to detect aflatoxin early, this review underlines the prospect of employing computer-based techniques to detect aflatoxin early. Because of these options, producers will be able to quickly detect aflatoxin contamination and, as a result, make informed decisions about how to prevent and/or reduce aflatoxin contamination, hence enhancing maize quality and storability.

Key Words: Aflatoxin-contamination, aflatoxin-management, temperature, humidity, optical-based, pre/ post-harvesting.
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1. INTRODUCTION

Aflatoxins are mycotoxins produced naturally by mold strains such as Aspergillus flavus and Aspergillus parasiticus [1, 2]. Cereals (maize, sorghum wheat, and beans), nutty (peanuts, cashew nuts), cotton, and fruits are among the crops they attack [3]. Because maize (Zea mays L.) is Tanzania's principal food crop, it has been used as a model crop in this research. A key food crop is consumed by more than 75% of the country's population [4]. It is also known to be a critical food security crop and a source of income for more than half of the country's population who live in rural areas.

Due to the influence of climatic factors such as (increased temperature and high precipitation) and biological factors such as insects and fungal contaminations, aflatoxin contamination commonly develops in maize during storage or/and processing. [3] as previously pointed out aflatoxin levels should not exceed 20μg/kg for human beings and 100μg/kg for animals [4]. Aflatoxin exposure is primarily obtained from the consumption of contaminated food, which is hazardous to both human's and animals' health. The chemicals can have severe and long-term harmful effects, posing substantial health risks to humans and animals. They can cause hepatotoxicity, teratogenicity, and immunotoxicity, among other things. [5,6].

Efforts to correctly identify infected grains to prevent harmful effects on humans have been initiated by some scholars [7]. In their study, they attempted to separate contaminated maize grains based on color and texture by sorting the grains with some fungal-

infected color. Other methods such as involving culturing of the fungus have been developed but they involve the destruction of grains for resolution and take a long time (up to 7 days) before the fungi are identified.

Furthermore, Higher-Performance Liquid Chromatography (HPCL), Thin Layer Chromatography (TLC), and Enzyme-Linked Immunosorbent Assays(ELISA) are the official standard methods readily presented for aflatoxin recognition and/or quantification [8]. All of these methods demand the use of specialized equipment as well as a lengthy extraction process. These methods are time-consuming, necessitate destructive sampling, and require expert personnel despite their high accuracy, sensitivity, and dependability. These drawbacks make it difficult to utilize regularly. [9].

As a result, numerous non-destructive approaches are blossoming in the agricultural area to interchange the traditional ways to overcome these issues. Hyperspectral imaging (HSI) is a promising technology for assessing the quality of a variety of agro-food items. It is a fast plus non-destructive technique for spotting aflatoxin in cereals, such as optical-based, which may be suited for real-time detection and fewer sample preparations [10, 11]. The main goal of this review was to create a baseline from the literature on the applicability of optical-based technology for improved detection and prevention of aflatoxin contamination and its effects on consumers. As a result, integrated methods and optical-based application in the maize price chains are being used to prevent aflatoxin contamination and reduce aflatoxin presence in the foodstuff system, with the overall impact of refining food safety and food safekeeping, which will eventually improve public health, nutrition, agricultural yield, and trade.

2. RELATED WORKS

2.1 Mechanism of the aflatoxin contamination in maize

Infection of maize is highly associated with pre and post-harvesting and poor storage practices [12]). About 95% of the farmers store their grains in-house using insect susceptible methods such as sacks which, also have been cited to be the main cause of aflatoxin-contamination [13]. The maize is contaminated during pre-harvest and under favorable conditions such as higher temperature, higher precipitation and moisture, and improper storage of food. Fungi, pests, and aflatoxins might be severe when conditions are disposed of, issues in grain storage systems. Aspergillus species present in decaying plants, the soil, and their spores are transferred via air streams and insects to crops and food rooms [14].

The increase in climate change effects is likely to increase the risk of aflatoxin-contamination in staple food example maize and as it is known that climate change influences pests and disease development [3]. Therefore when the weather conditions change and become warmer or precipitous while the maize is not well dried, stored, or packed the molds grown on the maize by spoil kernel and furthered more to the whole structure by contaminating part by part [15-17].

Developing innovative, optical-based methods is significant for aflatoxin management and prevention as food insecurity not only affects human health and its risk at large but also affects the social and economic aspects [18]. Optical-based techniques have been said to offer a lot of potential for online output since they have good outcomes for detecting aflatoxin and fungal contamination in future technologies. Thus, there is a necessity to derive innovative optical-based methods.

2.2 Aflatoxin detection methods

There are varieties of optical-based detection technologies that have been developed by various academics. [7, 19] see Table 1.

Table 1: Detection methods

Methods (purpose of study)	Working principle	Advantages	Challenges	References
1. One- and two-photon induced fluorescence spectroscopy were used to identify aflatoxins in maize.	Techniques for detecting aflatoxins via optical spectroscopic detection It can also assess the water content of items, detect color aberrations, and identify foreign objects in food streams using absorption and fluorescence spectroscopy, allowing them to be recognized optically.	The intrinsic fluorescence signal in both healthy and infected maize grains is diminished in time and accuracy.	Toxic pollutants in food or feed products are difficult to detect unless the contamination level is high and the approach is costly.	[20]
2. Classification of aflatoxin Contaminated Single Corn Kernels by Ultraviolet to Near-Infrared Spectroscopy (NIR).	Using the spectra and the aflatoxin concentration, to classify single corn kernels, the machine classified individual kernels to see the level of contamination and identification of aflatoxins in corns.	The models can accurately estimate the aflatoxin level of kernels by 95.3 percent and by every single kernel observed.	The spectroscopy system classifies single maize kernels tainted with aflatoxin from 304 to 1,086 nm, above or below which it cannot perceive.	[21]
3. Advances in nanomaterial-mediated bio and immunological sensors for aflatoxin detection in food products have recently been made.	In this study, the author uses different optical biosensors for the detection of aflatoxin in pistachio kernels such as Optical biosensors based on evanescent waves Optical biosensors that glow in the dark Optical biosensors with Chemiluminescence Optical colorimetric biosensors	The majority of studies suggest that biosensors proposed in the literature for aflatoxin testing have great stability, precision, and accuracy.		[22]
4. Application of multiplexing fiber-optic laser-induced fluorescence spectroscopy for detection of aflatoxin B1 contaminated pistachio nuts	The multiplexed fiber-optic laser-induced fluorescence spectroscopy (LIFS) system with one-, two-, and three-probes were used to detect intentionally aflatoxin (5, 10, 20, 30, and 50 particles per billion (ppb) contaminated 300 pistachio kernels, respectively.	The machine had the highest accuracy of 97.0 percent while using the spectral range of 390-660 nm.	Both the control and contaminated samples' spectral curves had a similar form and were overlapped, especially from the low-intensity samples.	[23]
5. Near-infrared hyperspectral imaging for	It detects the single contaminated kernel by using color texture when screened	Every single kernel near the machine was detected thus the	To eliminate the miscalculation of the residual	[24]

detecting Aflatoxin B1 of maize grains.	by light therefore fungus-infected kernels would disperse more light Green and red were used to represent healthy and infected kernels, respectively.	machine was very accurate by 92.3%. The majority of the kernels, on the other hand, were mislabeled for aflatoxin contamination, with those that were clear carrying nearly no or barely more than 20 ppb.	kernel, which was in the middle of health and contamination, sample preparation must be improved.	
6. Raman Spectroscopy for Aflatoxins in Maize: Rapid Detection.	Surface-enhanced Raman spectroscopy (SERS) was used to categorize and compute the level of aflatoxin in maize at concentrations of 0 to 1,206 µg/kg.	It has great possibilities to detect aflatoxin in maize compared to Near-Infrared NIR spectroscopy and has higher sensitivity when contaminated maize passes mostly between below and above 20 µg/kg samples.	According to the study, conventional Raman spectra generated from the same samples were significantly weaker than SERS spectra, and they shifted in different SERS spectral areas.	[25]
7. Aflatoxins and fungal contamination in agricultural goods have recently been detected using optical approaches that are quick and non-destructive.	The author compared three optical mechanisms for the detection of aflatoxin in maize, which is Near-infrared spectroscopy, which uses chemicals for the testing. Fluorescence spectroscopy was it worked on the principle of light emission to absorption of UV light. With kernel with aflatoxin will irradiate blue-fluorescence light. Moreover, hyperspectral imaging incorporates spectroscopic and imaging systems to produce information.	They are a promising and helpful method for detecting dangers and chemical components.	The approaches are highly complicated, and they may collide with analytical data.	[11, 26, 27]
8. Using short wave infrared (SWIR) hyperspectral imaging, aflatoxin B1 (AFB1) was detected in individual maize kernels.	The mechanism uses characterized wavelength of (1000-2500) nm to detect the infection grains and differentiate the health one by hyperspectral imaging.	The imagery was cleansed by 95.45%, and the tainted kernels were detected. It's a quick and precise mechanism.	The process detects a single kernel thus needs to be improved.	[9, 10]
9. A technique for examining aflatoxin B1	When the contaminated illuminated blue fluorescence and the normally illuminated	The mechanism was accurate and fast by 96.9% by both	Challenge slight-confusion was observed with a	[8, 11]

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(AFB1) on corn kernels using short wave infrared (SWIR) hyperspectral imaging	red fluorescence were passed under UV irradiation, both infected and healthy kernels were screened using SWIR hyperspectral over the spectral range of (1100-1700) nm.	calibrated and validated sets.	kernel of 10μg/kg.	
10. Classification of corn kernels contaminated with aflatoxins using fluorescence and reflectance hyperspectral images analysis	The mechanism uses (VNIR) under the characterized wavelength of (700-800) nm for screening both germ and endosperm less and higher than 20ppb using fluorescence reflectance and hyperspectral images.	The highest overall accuracy was 92.67 percent for germs greater than 20ppb, and 86.67 percent for endosperms greater than and less than 20ppb.	For germ kernels less than 20ppb, the accuracy percentage performance was low, implying that the kernels should be more contaminated for quick screening.	[26, 28]
11. Aflatoxin detection at the pixel level in maize using feature selection and hyperspectral imaging	Using transmittance and reflectance spectroscopy, HIS discovered aflatoxin in corn. To extract feature bands, the author employs three methods, one of which involves selecting four hyperspectral bands from previous articles: 390 nm, 440 nm, 540 nm, and 710 nm. Another way is to compress the hyperspectral volume by using feature extraction PCA to acquire the first 5 pcs, and the third method is to use (Fscnca, Fscmrmr, Relieff, and Fishier algorithm) to choose the top 10 feature bands to display either clean or contaminated.	The approaches were accurate to the tune of 89.51 percent, 93.83 percent, and 99.38 percent. As a result, the third method is the most accurate of all. The color red represented the contaminated, while the healthy kernels were represented by the color blue.	It will take more time to determine if a pixel is aflatoxin-contaminated or not.	[29, 30]

3. FRAMEWORK OF OPTIC SENSOR AND COMPUTER TECHNOLOGY

This part describes the working principles of optical sensors and the imaging in aflatoxin detection.

3.1 How the optical-based technology can be used for early diagnosis, Aflatoxin management, and prevention.

The current state of development of quick and non-destructive optical-based detection technologies for aflatoxin detection in foods, such as LIFS, SWIR, NIR, and HIS imaging, has also been discussed. [27, 31], see Figures 1 and 2 below.
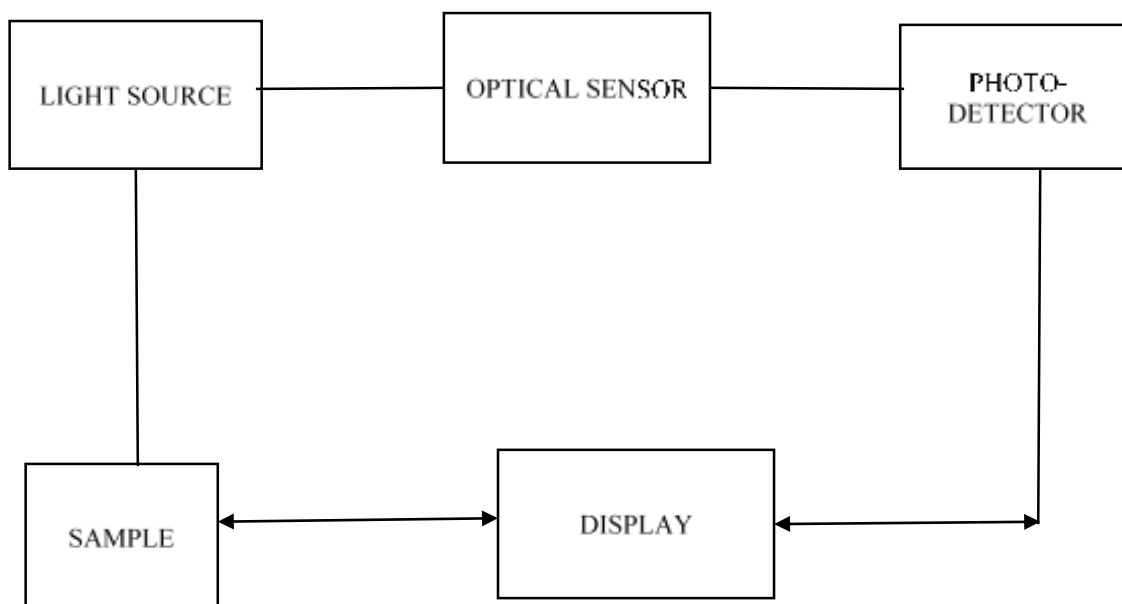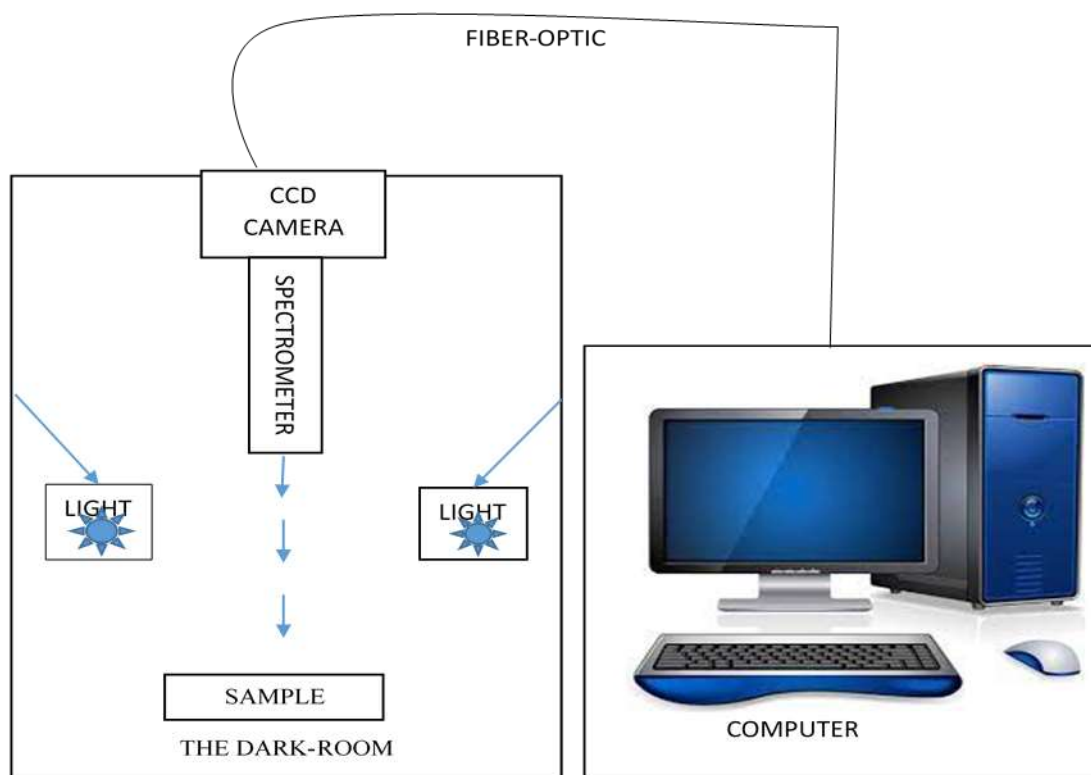

Figure 1: Conceptual framework by using fiber optical-sensor

The figure above has four parts the Light source can be [Emitting Diodes (LED) or Laser Diodes (LD's)] sensing part and photo-detector. Optical sensors are sensors that respond optically to the concentration of analyses in a model. , and they can categorize in the function of the optical property that has been measured: absorbance, reflectance, fluorescence, phosphorescence, luminescence, Raman dispersion, evanescence, refraction index [32].

 LED is a semiconductor light source that generates light when current flows through it, and a photodetector is an electronic device that gives an electrical signal based on received light signals [33, 34]

A light source is required to electrify the fiber system, which includes the optical sensor– and a photodetector is required to read the light released by the sensing region, which comprises data about the sample and detecting information [35]. Optical fibers monitor the light from the excitation source to the sensing zone and from the sensing zone to the optical detector thus, the optical sensor senses chemical, biological, and physical changes of a sample by interaction through light intensity. Finally, the intended information can be seen at the display screen in a mode of electronic signals [35].

Figure.2. Conceptual framework by using a color imaging system

A color imaging system consists of a frame-grabber for picture acquisition, a sample holding stage, a Charge-Coupled Device (CCD) camera for image capture and conversion, a light source for accurate illumination, and a processer hardware and software for image processing [36]. The incident detectable band light falling on a partially reflecting surface of the sample produces a digital image [37]. The photons are collected in the camera lens, converted to electrical signals by a CCD, and then saved on a hard disk for image display and analysis [38].

3.2 Applicability potential of optical-based technologies in Tanzania

Recent studies demonstrate that using optical-based and hyperspectral-imaging technology for the accurate assessment of more food products has a bright future. Moreover, the analysis of using an optical-base system on the worth, safety investigation, and valuation grains, also, there are many other foodstuffs whose quality factors were effectively resolute based on these techniques in recent years such as meat, fish, fruits, and vegetables [39].

Optical-based aflatoxin management and prevention have several advantages over traditional mold management methods, including being less time-consuming, more accurate, more convenient, and more dependable. However, there are just a few strategies for determining the validity and reliability of computer-based prevention methods. In Tanzania, very adequate technologies for screening aflatoxins, such as optical-based and hyperspectral-imaging mechanisms, are still available on the market, as the systems are seen as essential in improving trade efficiency related to materials, modern agriculture, product processing, and management activities [40]. Experts predicted that its novel use of optical-based technologies would lower the threat of aflatoxin contamination in our harvests and increase yields. Finally, items will meet customer expectations and assist the food sector in better understanding and controlling the quality and safety of food.

4. CONCLUSIONS

Farmers' value preserving what has already been generated by employing HIS, computer control, smart agriculture, and internet of things applications throughout storage and pre-and post-harvesting, hence minimizing human workload. This study focuses on various scientific research findings on aflatoxin governor in nutrition and feedstuffs at the pre-and post-harvest levels, as well as optical-based processes.

Aflatoxin contamination is common during pre-harvesting, post-harvesting, and storage, so following excellent agricultural practices, preventing fungal development in storage and the field, and maintaining proper temperature and relative humidity in silos and bags are all important. Improved bags, higher-quality herbicides and insecticides, and good maize harvesting and drying procedures will all result in high-quality crops with nil or low aflatoxin contamination. Our farmers and the people of Tanzania would benefit greatly from the use of computer-based and innovative technologies for aflatoxin screening. Not only the internet of things is used for real-time monitoring, observing, and sensing of parameter changes (temperature, precipitation, and humidity) in stores, but smart agricultural systems are also being used in maize farms.

Monitoring crops during storage by keeping optical sensors for moisture and temperature sensing is also important to reduce aflatoxin because water moisture and temperature are significant factors in fungal growth. Developing automatic control measures would improve storage stability in staple foods and real-time observing during pre and post-harvesting of cereals. If maize is not treated carefully during transportation and storage before reaching the final customers, it will be infected with aflatoxin.

As a result, leveraging and implementing the internet of things to track temperature and humidity in Lorries will be a huge success. Furthermore, knowledge of handling and control is still vital for aflatoxin food protection, and more procedures that are effective are needed to prevent contamination, as it is impossible to be aflatoxin-free, but we can handle to reduce aflatoxin levels during the storage and supply chain.

CONFLICTS OF INTEREST

On the submission of this work, the authors certify that they have no conflicts of interest.

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