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Development of a UV-based Imaging System for Real-Time Detection and Separation of Dried Figs Contaminated with Aflatoxins

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ABSTRACT

The risks of diseases and economical losses resulting from aflatoxin contamination to the agricultural products are a significant problem. In this study, a prototype system for real-time detection and separation of dried figs contaminated with aflatoxins was developed and tested. The main components of the system are 365 nm wavelength UV light sources, CCD cameras, optical sensors, image processing and automation software, belt conveyors that carry dried figs, and automatic separation units in a dark room. Four UV black-light lamps were installed on the aluminum roof of both the belt conveyor systems, to enhance the effectiveness of reflective illumination of the dried figs in the detection leg of the process. The monitoring set up consisted of two cameras with high resolution and low distortion 9 mm lenses, and two CCD color sensors. The imaging system, which had an exposure time of 8.12 ms, could capture images of dried fig samples moving on the belt at speeds of 0.18 m s⁻¹ and 0.06 m s⁻¹ for belt 1 and belt 2, respectively. The system uses two cameras, as both sides of the dried figs were required to be scanned. Figs contaminated with aflatoxins can be separated pneumatically, by an automatic separation system. The prototype system was tested by using 400 dried figs. The prototype system achieved a 98% success rate in the detection and separation of the dried figs contaminated with aflatoxins. Turnover efficiency and hourly machine capacity of the system were calculated as 82% and 34.56 kg/h, respectively. Additionally, total system efficiency was calculated as 80.36%. Thus, the system was found effective and convenient for real-time detection and separation of the dried figs contaminated with aflatoxins.

Keywords: Aflatoxin detection; Dried fig; UV reflection; Real-time image processing

Aflatoksinli Kuru İncirlerin Gerçek Zamanlı Tespiti ve Ayrılması İçin UV Görüntüleme Sisteminin Geliştirilmesi

ESER BİLGİSİ

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ÖZET

Tarımsal ürünlere aflatoksin bulaşmasından kaynaklanan hastalık riskleri ve ekonomik kayıplar önemli bir sorundur. Bu çalışmada; gerçek zamanlı aflatoksinli kuru incirin tespiti ve ayrılması için bir prototip sistem geliştirilmiş ve denenmiştir.

Karanlık bir odada bulunan sistemin temel parçaları; 365 nm dalga boyuna sahip UV ışık kaynakları, CCD kameralar, optik sensörler, görüntü işleme ve otomasyon yazılımları, kuru incirleri üzerinde taşıyan bantlar ile otomatik denetimli ayırma üniteleri şeklindedir. Sürecin algılama bölümünde; kuru incirlerin ışık yansıtma etkinliğini arttırmak için, her bir taşıyıcı bant sisteminde alüminyum bir çatı üzerine yerleştirilmiş dört adet UV siyah ışık lamba bulunmaktadır. İki kameradan oluşan görüntüleme düzeneği; yüksek çözünürlüklü ve düşük bulanıklığa sahip iki adet 9 mm lens ve iki adet CCD renkli algılayıcıdan oluşmaktadır. 8.12 ms'lik pozlama süresine sahip olan görüntüleme sistemi; görüntüleri, hareket halindeki kuru incir örneklerinden 0.18 m s⁻¹ birinci bant ve 0.06 m s⁻¹ ikinci bant hızlarında alabilmektedir. Kuru incirlerin her iki yüzeyini de tarayabilmek için, sistemde iki adet kamera kullanılmıştır. Aflatoksinli incirler; otomatik bir ayırma sistemi kullanılarak, pnömatik olarak ayrılmıştır. Prototip sistem, 400 adet kuru incir kullanılarak test edilmiştir. Prototip sistem, aflatoksinli kuru incirlerin saptanmasında ve ayrılmasında % 98 başarı oranına ulaşmıştır. Sistemin çevirme etkinliği % 82, saatlik makine kapasitesi ise 34.56 kg h⁻¹ olarak hesaplanmıştır. Bunlara ek olarak, toplam sistem etkinliği % 80.36 olarak hesaplanmıştır. Böylece sistem, aflatoksinli kuru incirlerin gerçek zamanlı tespiti ve ayrılması için etkili ve uygun bulunmuştur.

Anahtar Kelimeler: Aflatoksin tespiti; Kuru incir; UV yansıtma; Gerçek zamanlı görüntü işleme

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1. Introduction

Aflatoxins, which are toxic metabolites of the *Aspergillus flavus* and the *Aspergillus parasiticus* fungi, are naturally occurring food contaminants. Aflatoxins can affect a wide range of commodities including cereals, oilseeds, spices and tree nuts, as well as milk, meat and dried fruits (WHO 2005). These fungi are capable of growing when the conditions of temperature, relative humidity, and moisture are favorable (Iamanaka et al 2007). Well-known within the agricultural community, aflatoxins have been studied for over forty years due to their widespread occurrence and their significant impact on the crops (WHO 2005). Aflatoxins are considered to be the most toxic metabolites among the mycotoxin classes, and pose a potential risk to human and animal health. Aflatoxin B₁ is known to be a potent hepatocarcinogen for humans (Iamanaka et al 2007). The World Health Organization (WHO) hosted a workshop to create an integrated plan, intended to generate culturally appropriate, long term public health strategies, to reduce the aflatoxin exposure in the developing countries (WHO 2005).

Aflatoxin was first reported in 1961 in peanuts. Aflatoxin has been commonly associated with peanuts, cereal grains, cotton seed meal, and milk from animals that have consumed such seeds (Buchanan et al 1975). Dried figs exported from Turkey are sometimes rejected because of aflatoxin

contamination. If this issue is evaluated from similar points of view for Turkey, the first study in Turkey on aflatoxins in hazelnuts was conducted in 1967. Shelled hazelnuts exported to Canada and the United States of America were rejected because they contained aflatoxins (Heperkan 2006).

Aflatoxigenic fungi grow on fig fruits during their growth, ripening, and drying phases, but they thrive especially during the ripening and the over ripening phases. Toxigenic fungi may grow and form aflatoxins on the outer surface or inside the cavity even if no damage occurs on the skin. The critical periods for aflatoxin formation in dried fig fruits start with the ripening of figs on the tree. It progresses during the over-ripening period, when they lose water, shrivel and fall down onto the ground, and continues until they are fully dried on drying trays (Embaby et al 2012). Both the skin and the inner cavity of the fig fruits can be contaminated by the fungi. Fungal growth and the subsequent mycotoxin production are influenced by a variety of complex interactions between intrinsic and extrinsic factors, as well as stress factors and physical damage. The intrinsic factors include moisture content or water activity (a_w), pH, redox potential (E_h), nutrient content (substrate), inhibitors and osmotic pressure. The extrinsic factors are related to environmental conditions such as temperature, relative humidity (ERH) and gases

in the environment. Factors promoting mycotoxin production can differ from mould to mould. It has been reported that mycotoxin production begins on the tree. Even if the a_w values during the drying phase are found to be safe, rain or dew during drying can lead to an increase in the moisture levels in the dried figs. Further development of toxigenic fungi and mycotoxin production can be observed in such cases. Climatic conditions such as high humidity, moderate temperatures and sudden rains may also promote fungal growth. In addition to the drying stage, storage is another important critical stage that is susceptible to mycotoxin production (Heperkan et al 2012).

It has been reported that dietary aflatoxin exposure in parts of Africa and Asia has been associated with primary liver cancer, especially in hosts with chronic Hepatitis B Virus (HBV) infection (Perz et al 2006).

In recent years, spectral imaging techniques have been developed for scanning agricultural and food products. Scientists use two main approaches: the line scan approach and the area scan approach, for capturing spectral images (Qin et al 2012). The line-scan image acquisition technique was used for automated detection of pistachio defects by machine vision (Pearson et al 2001) and in the eggplant grading machine (Kondo et al 2005). Applications based on the area-scan technique include detecting peel defects, grading fruits based on surface defects, and inspecting fecal contamination of animals. The UV-fluorescence imaging technique has been selected for detecting areas on dried figs that are contaminated with aflatoxin (Özlüoymak 2012). For this application, an important band (i.e., 365 nm) for inspecting aflatoxin contamination was identified during UV band selection (Steiner et al 1988).

A new method for separating pistachio nuts contaminated with aflatoxins, based on processing the picture under a 365 nm UV light was introduced by using neural network (Karami & Mirabolfathy 2006). The UV absorption by aflatoxins was monitored in a GY agar medium using UV photography. In the UV photographs, aflatoxin-

producing molds were identified as gray or black colonies, whereas moulds not producing aflatoxins appeared as white colonies (Yabe et al 1987).

Nowadays, products contaminated with aflatoxins are separated using traditional methods in dark rooms by humans. These methods are labor-intensive and require a lot of time. In the traditional separating process, the emission of green radiation by the figs contaminated with aflatoxins when placed under UV light is beneficial. Being invisible in daylight, aflatoxin contamination cannot be seen without the aid of the UV light. Figs contaminated with aflatoxins are separated manually.

The main aim of this study is to develop a prototype real-time detection and separation system for dried figs contaminated with aflatoxins.

2. Material and Methods

2.1. Material

2.1.1. Real-time detection and separation system to manage aflatoxin contamination

A real-time detection and separation system for aflatoxin contamination was designed, manufactured and set up in a darkened laboratory (Figure 1), as aflatoxin contamination can only be seen in the dark, under UV lighting. The machine has a small scale conveyor belt system, consisting of optical inspection and pneumatic separation units, in an empty chamber. In order to be able to examine the effects of aflatoxins on the dried figs for the determination of contamination, two identical machines were produced. These machines can transport dried fruits on the conveyor belt with a 0.37 kW 3 phase 4 pole electric motor (GAMAK, AGM714b), at an adjustable speed using component drives (ABB micro drives, ACS150). The suitable speed for the dried figs on the conveyor belt was determined through experimentation.

Aflatoxin contamination can be found on both sides of the fig. Being a flat fruit; the fig must be checked on both sides. Consequently, the conveyor belt system was designed to have two progressive

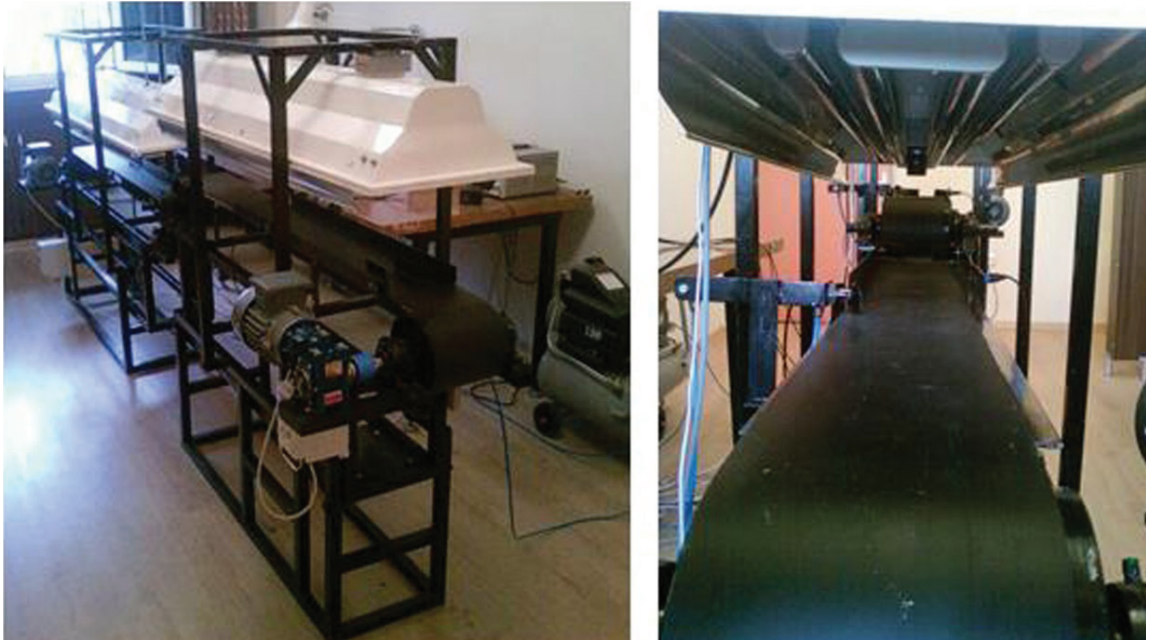


Figure 1- Aflatoxin contaminated dried fig separating machine

Şekil 1- Aflatoksinli kuru incir ayırma makinası

stages. There are two belt conveyors in series. One side of the fig is analyzed on the first belt conveyor. When the fig proceeds to the second conveyor, it is flipped and turned upside down. This facilitates the inspection of the other side of the fig. Thus, with the help of a dual conveyor belt system (Figure 2) that facilitates the flipping of flat figs, both sides of the fig can be inspected. A schematic diagram of the aflatoxin contamination detection and separation system is illustrated in Figure 3. Basically, it consists of a system control unit, a lighting unit, a camera unit, and a separation unit.

System control unit (SCU): The system control unit comprises of a data acquisition card (National Instruments, NI USB-6009), a computer equipped with a fire-wire PCI card (Allied Vision Technologies, FW-PCI3201), a relay card, a voltage divider circuit card and a DC power supply. The fruits passing in front of the optical sensor trigger the camera. The captured images are then transferred to the computer. According to the decision for dried

figs, pneumatic kickers could be controlled by using the system control unit. The optical sensors detecting the fruits generate an output signal. By using the divider circuit card; this signal level, which is sent to the cameras, was restricted to a maximum of 5 V. According to their positions on the conveyor belt in the field of view, images of moving dried figs captured by the cameras can be sent to the computer. Fire wire cables are used for transferring the image data between the cameras and the computer. 8-pin I/O cables (Allied Vision Technologies, 8-pin HIROSE), compatible with AVT Guppy series, were used for triggering the cameras. As seen in Figure 4, the DC power supply, the UV lamps and the motor drives can be controlled by using the LabVIEW interface as well. A system software (Figure 4) was developed for building real-time machine vision applications by using the LabVIEW Professional Development Module and the Vision Development Module (National Instruments).



Figure 2- Dual conveyor belt system designed for figs dried

Şekil 2- Kuru incir için tasarlanan çift bantlı taşıma sistemi

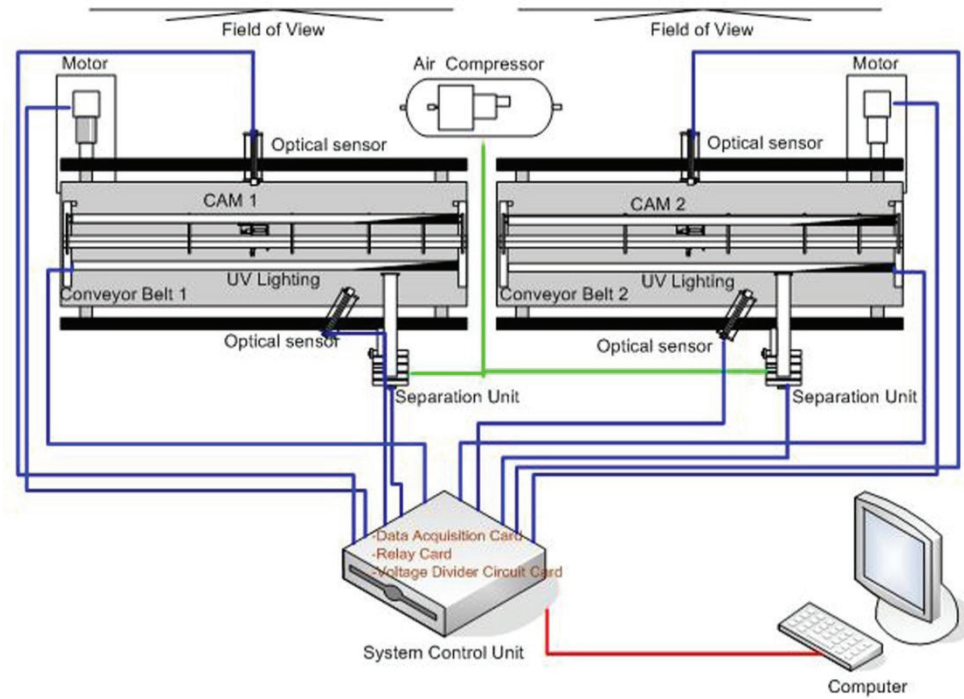


Figure 3- Schematic diagram of the aflatoxin contamination detection system

Şekil 3- Aflatoksin tespit sisteminin şematik gösterimi

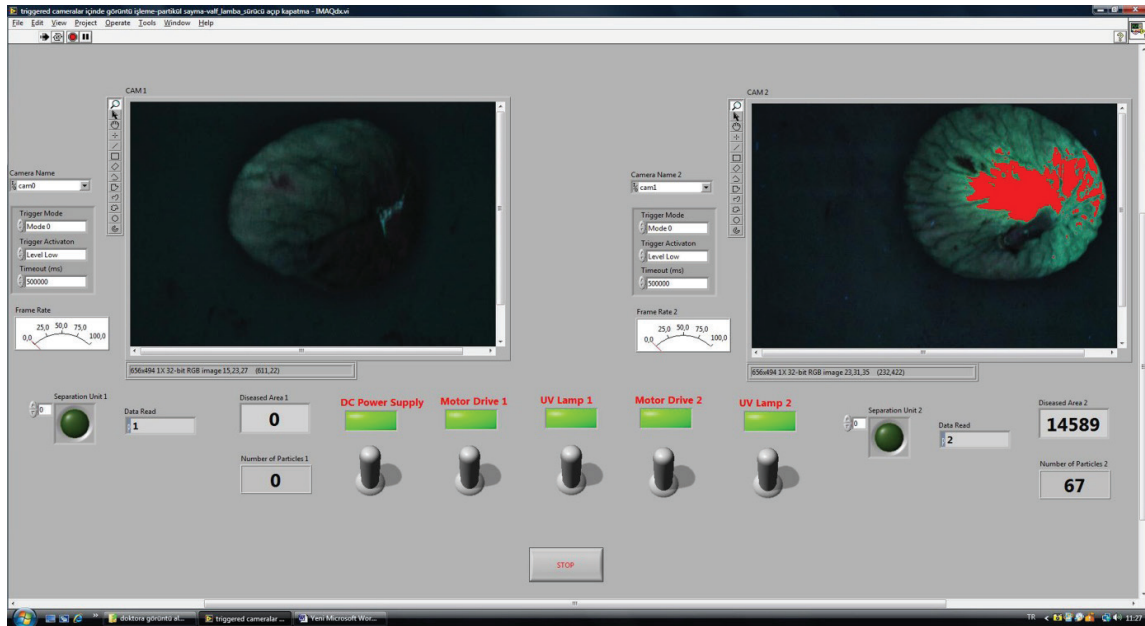


Figure 4- LabVIEW real-time user interface

Şekil 4- LabVIEW gerçek zamanlı kullanıcı arayüzü

The Lighting unit: The lighting unit, which comprises of four 36W UV black-light lamps (Philips, TL-D/08), is placed parallel to the moving direction of the conveyor belt. A dome reflector, which is constructed with aluminum, is located above the UV lights to irradiate uniform reflectance illumination onto the dried figs in the detection area.

The Camera unit: In area-scan imaging, a camera is used to capture the image of a specific area. The area-scan method was chosen because of its highly configurable capabilities for acquiring, analyzing, and logging images over a two-dimensional scanning area for the detection of aflatoxin contamination. 9 mm lenses are chosen for the optical system for the cameras. The cameras used in the system were produced by Allied Vision Technologies and the lenses were manufactured by FUJINON. To capture color images, two identical FireWire (IEEE 1394a) color cameras (AVT Guppy F-033 C) were used. Each camera has a 1/3" CCD sensor (SONY IT CCD ICX424AL/AQ), with a maximum resolution of 656 (H) x 494 (V) (full frames). To increase the real-time

detection accuracy, both cameras for the detection system were fixed to work in Format 7-Mode 0, Bayer RG 8 pixel format, with an exposure time of 8.12 ms. The frame capture rates of the cameras can be moved up to 58 fps with a resolution of 656x494 (effective picture size-full frame). Cameras on the system acquired images at 0.58 fps for belt 1 and 0.28 fps for belt 2, respectively. The time required for the image processing in the system was 2.456 ms, on the developed software. The image processing process was repeated a 1000 times on a trial basis to ensure the accuracy of the imaging system time. A Dell Studio XPS 435MT desktop computer was used for the system software. This computer has an Intel Core i7 CPU and image processing was achieved on this machine. It should be noted that the time required for the image processing process may vary from processor to processor according to the computer's processor speed. The focal length of the camera unit was 9 mm, and the working distance (the distance between the lens and the top of the sample being observed) was 160 mm. The imaging

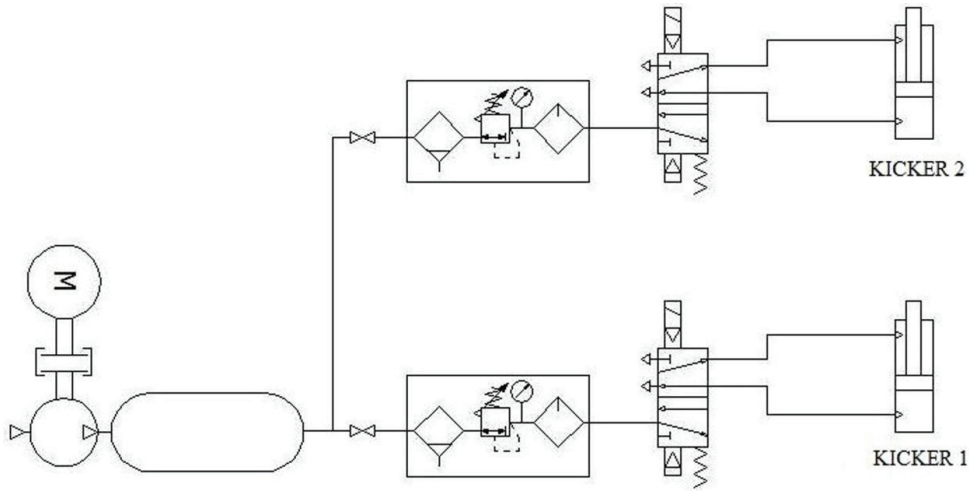


Figure 5- Pneumatic separation unit wiring diagram

Şekil 5- Pnömatik ayırma ünitesi devre şeması

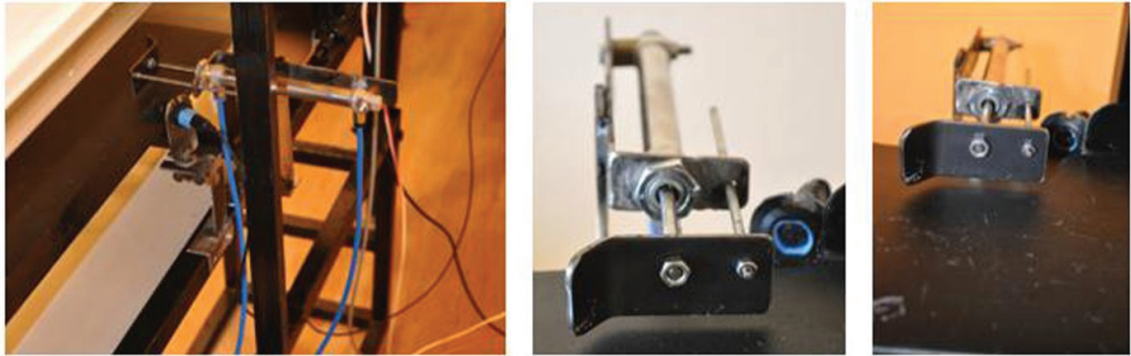


Figure 6- Pneumatic controlled separation unit

Şekil 6- Pnömatik kontrollü ayırma ünitesi

system's view area was calculated as 91.1 mm x 68.6 mm with a spatial resolution of 7.2 pixels mm⁻¹ (182.88 dpi). The imaging system does not capture regions outside of the camera's sight. Besides, an optical sensor (SICK, MHT15-P2347) was used to trigger the cameras.

The Separation unit: In order to remove the dried figs contaminated with aflatoxins from the conveyor belt system, a pneumatically controlled separation unit was designed and fabricated for each line. The equipment of the separation unit comprises of an

optical sensor (SICK, MHT15-P2347), a pneumatic cylinder (TEKMAK), an electro-pneumatic converter (STNC, TG2521-08), a lubricator (STNC, TC 2010-02), and an air compressor (Typhoon, TW2501-24). This unit was designed for each line to operate separately and independently from each other and the pressure line of both conveyor belts was fed from its own resources. The wiring diagram of the pneumatic separation unit is shown in Figure 5. The separating system is controlled by the System Control Unit (SCU), and each line is equipped with

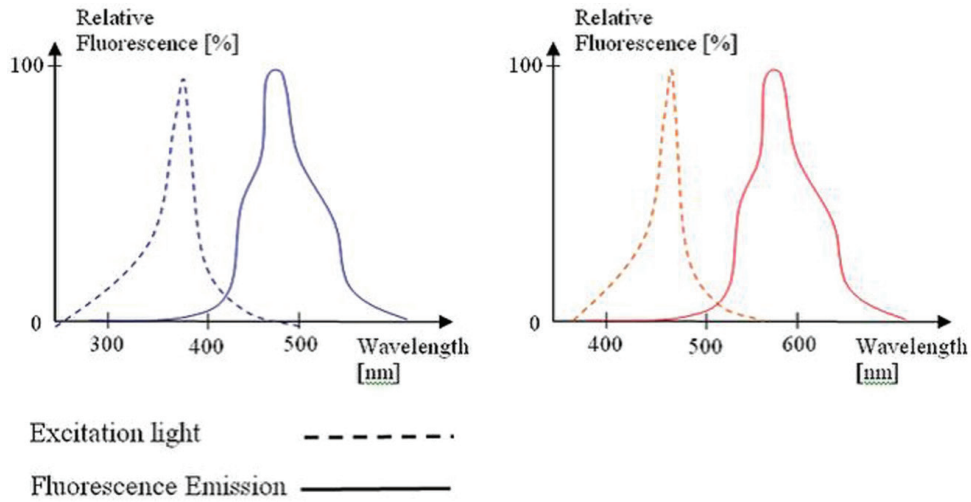


Figure 7- Fluorescence excitation and emission principle (NI 2008)

Şekil 7- Floresans uyartım ve saçınım prensibi (NI 2008)

a pneumatic kicker triggered by an optical sensor (Figure 6) using the system software.

2.2. Methods

2.2.1. Automated fluorescent imaging techniques

There are many benefits to using fluorescence instead of the regular visible light. Firstly, the basic principles of fluorescence excitation and emission must be known. Fluorescent compounds or fluorophores are capable of absorbing light at one wavelength and emitting light at a longer wavelength. When a fluorescent compound absorbs a photon, its outer shell of electrons move from a 'ground' state to an 'excited' state. It can both release this energy as thermal radiation and return to the ground state, or it can release part of the energy to its molecular environment and then emit a photon with less energy and consequently a longer wavelength (NI 2008).

As mentioned, the light emitted as fluorescence is at a higher wavelength (lower energy) than the incoming excitation light. This concept is illustrated in Figure 7. The biggest advantage of using the fluorescence method is the ability to detect extremely

small amounts. This is because fluorescence, with the appropriate filters, measures a light source on a perfectly black background (NI 2008).

In this system, the dried figs were exposed to the 365 nm wavelength UV light source. Thus, aflatoxin on the diseased fruits emitted a longer wavelength by absorbing the light. Thus aflatoxins, which are invisible in daylight (outside the limits of human vision), were rendered visible. Regions with aflatoxin become visible, radiating bright greenish yellow fluorescence under UV light (365 nm).

2.2.2. Image processing and classification method

Figure 8 summarizes the image processing and classification algorithms for the detection of aflatoxin contamination in dried figs. After acquiring the original images from the cameras, image buffering functions of the system software are used for retrieving again to image masking images. To segregate aflatoxin contaminated areas, the thresholding method is applied to the image after image buffering. Image masking is applied to the acquired binary image, which is obtained by using the binary image inversion method. A dried fig mask image is produced when applying original fruit

images and aflatoxin contaminated area images. A final decision is then taken on the condition of aflatoxin contamination in the fig, after applying all the image processing processes. The times required for determining and separating dried figs with aflatoxin contamination were 1.83 s for belt 1 (at belt speed of 0.18 m s⁻¹) and 2.73 s for belt 2 (at belt speed of 0.06 m s⁻¹), respectively.

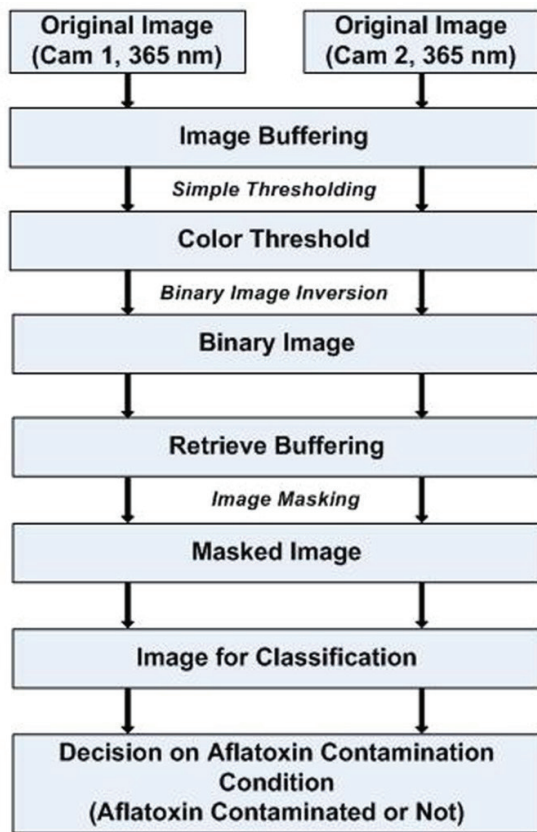


Figure 8- The flowchart of program used for detection of dried figs contaminated with aflatoxin

Şekil 8- Aflatoxinli kuru incirlerin tespiti için kullanılan program akış şeması

In this study, the most well-known “image thresholding method” among the image processing techniques was used. Thresholding consists of segmenting an image into two regions—a particle region and a background region. In its simplest form, this process works by setting to white all pixels that

belong to a gray-level interval, called the threshold interval, and setting all other pixels in the image to black (NI 2006). Object and background pixels have intensity values grouped into two dominant modes. One obvious way to extract the objects from the background is to select a threshold, T , which separates these modes. Then, any point (x,y) in the image at which $f(x,y) > T$ is called an object point. Otherwise, the point is called a background point. In other words, the segmented image, $g(x,y)$, is given by

$$g(x,y)=1 \quad \Rightarrow \quad f(x,y) > T \quad (1)$$

$$g(x,y)=0 \quad \Rightarrow \quad f(x,y) \leq T \quad (2)$$

Where; $g(x,y)$ is the processed image obtained by using thresholding method; $f(x,y)$ is the pixel value of the image on the x th column and y th row; T is the selected thresholding value (Gonzalez & Woods 2007). The resulting image is referred to as a binary image. For color images, three thresholds must be specified, one for each color component.

A sample is considered as having aflatoxin contamination if there are remaining red pixels in the final image. Decision on the level of aflatoxin contamination is taken according to the calculated diseased area in the form of pixels and number of particles with aflatoxin. Otherwise, the system decision about the sample is uncontaminated.

2.2.3. Real-time aflatoxin detection for dried fig samples

The aforementioned image processing and classification methods were ratified by determining aflatoxin affected regions on dried figs. As shown in Figure 9, to accomplish the detection of aflatoxin contamination, real-time decision procedures for dried fig samples moving on the conveyor belt were developed. The output trigger signals produced by the optical sensors activated the cameras and then the captured images were transferred from one sample to the computer. Only one surface of the fig (e.g., ‘X’, or ‘Y’) was captured by each camera (Figure 9). Decision for each conveyor belt was independent and the kickers were controlled according to this decision,

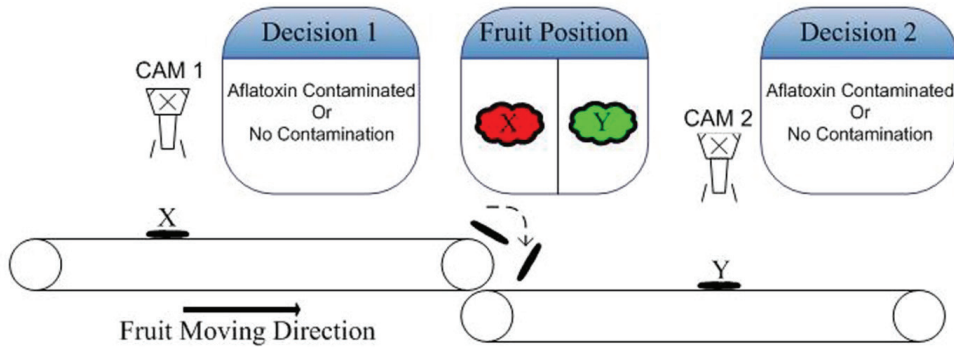


Figure 9- The real-time decision procedure for dried figs in action

Şekil 9- Hareket halindeki kuru incirler için gerçek zamanlı karar verme yöntemi

to separate the figs with aflatoxin contaminated. If the result for a fig sample was ‘Uncontaminated’, it would pass the kickers and drop to a bin at the end of the line. If the result for a fig sample was ‘Aflatoxin Contaminated’, the fig sample would be kicked off the belt conveyor.

It should be noted that only the front or the back faces of each fruit could be covered by each camera unit. In the course of the experiment, several dried figs were placed on the first conveyor belt, moving at a speed of 0.18 m s^{-1} . To provide for an accurate return action of the fruit, the second conveyor belt was set to move at a speed of 0.06 m s^{-1} . Thus, images of the diseased areas on the fig could be captured when the figs were moving on the conveyor belt. As the samples were being placed one by one manually on the conveyor belt and as the surface inspection was only partial, the system didn’t fulfill the real-life requirements for aflatoxin inspection. In this study, the author has tried to design a new system for the detection of aflatoxin contamination. The main aim was to test the effectiveness of the methodology and the suitability of the software and hardware of the prototype. In the future, by considering the new modifications for the detection system (e.g., by using side-angle cameras per unit to scan lateral sides of the figs), the inspection capacity of the system will be increased for the entire surface of each fig.

2.2.4. The preparation of dried fig samples

The real-time aflatoxin contamination detection system was tested using dried figs (*Ficus carica*). Fruit samples were obtained from an exporting company in İzmir, Turkey at the end of the drying season of 2012. The samples with healthy surfaces, and diseased surfaces were manually separated by human inspectors in the company. The dried fig samples were separated into two categories as ‘Contaminated’ and ‘Uncontaminated’. 200 diseased dried figs were selected from the ‘Contaminated’ class, and 200 healthy dried figs were selected for the ‘Uncontaminated’ class. Thus a total of 400 dried figs were tested on the developed system. Prior to the tests, the fig samples were stored in a refrigerator at a temperature of 4°C . About 1 hour before the test, the figs were removed from the refrigerator so that they were in equilibrium with the room temperature.

3. Results and Discussion

3.1. Image processing results

Fluorescent sorting with the image processing algorithms was examined and aflatoxin contaminated figs with the property of “bright greenish yellow” fluorescent excitation were determined. To recognize the “bright greenish yellow” color of contaminated figs, a dark room was designed with 365 nm

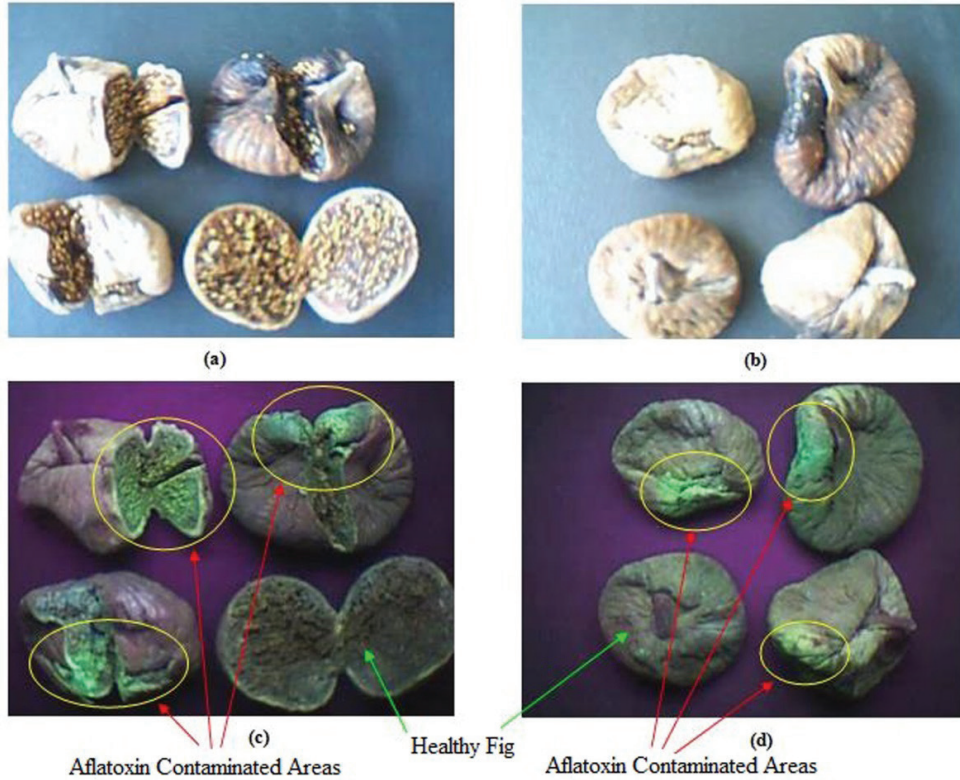


Figure 10- Sample photographs taken for detection of aflatoxin formation on dried figs

Şekil 10- Kuru incirler üzerindeki aflatoksin oluşumunun tespiti için çekilen örnek fotoğraflar

wavelength UV lamps, and sample images were taken with the camera. After the capturing process, pictures of figs with aflatoxin contamination were analyzed and the areas with aflatoxin were detected using digital image processing techniques.

Aflatoxins radiate by showing phosphorescent properties on the wavelength of 365 nm. As shown in Figure 10(a) and (b), in the photos taken in daylight, no difference can be seen between the figs. However, as shown in Figure 10 (c) and (d), in the pictures of the same fruits captured in a dark environment with UV lighting, areas on the figs contaminated with aflatoxins became visible. In other words, while healthy figs didn't radiate under the UV lighting, contaminated figs radiated "bright greenish yellow" color.

The color thresholding method was applied to obtain images in the RGB (Red, Green, Blue) format. A new image was obtained by overlaying the threshold image back onto the original image. This process is known as "masking" in the image processing parlance. In this way, the masking process was completed by overlapping the original image and the processed image. Color parameters used in the system were determined for the red color in the range of 0-255, for the green color in the range of 0-155, and for the blue color in the range of 0-180. The combination of these color parameters provided the thresholding value of the system for "bright greenish yellow" color. This process was performed in Labview for 2.456 ms, by looking for areas over a certain threshold fluorescence that were greater than a certain threshold mass.

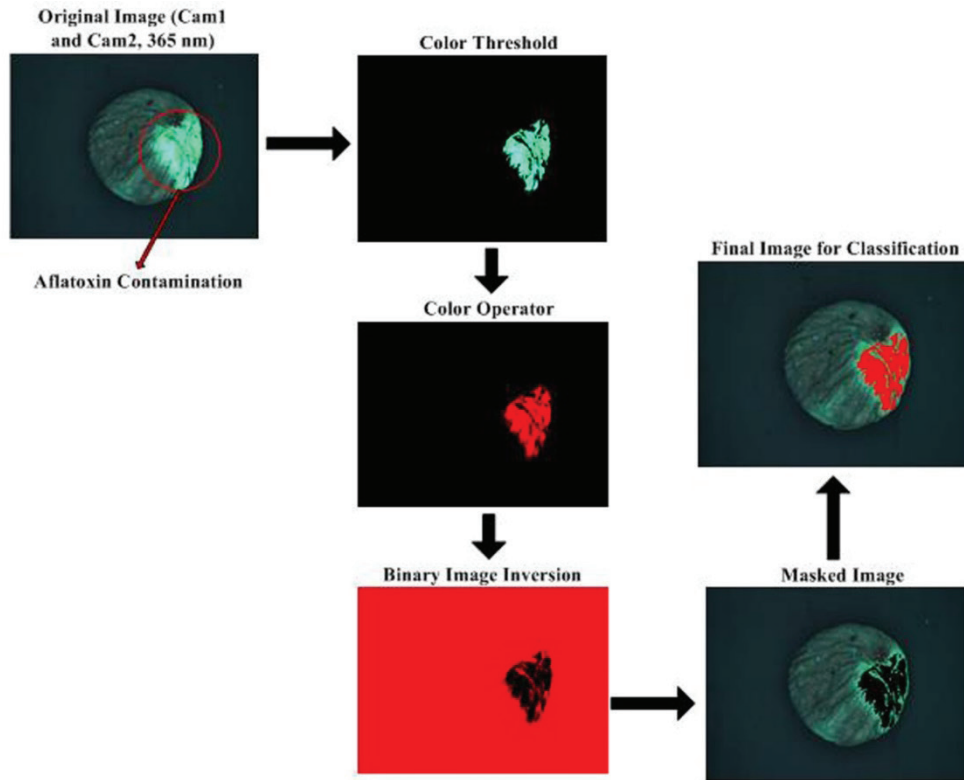


Figure 11- Identification of aflatoxin contamination on the dried fig using thresholding method

Şekil 11- Eşikleme yöntemi kullanılarak kuru incir üzerindeki aflatoksinin saptanması

Figure 11 demonstrates the major processes of the image processing and classification method for identifying aflatoxin contamination. The masked image was obtained from the thresholded image, and the background of the original image was removed. Aflatoxin contamination of the fig was marked with red in the masked image and other areas (e.g., dried fig peel, background of conveyor belt, and some other defects and diseases) were darker than the aflatoxin contaminated areas. Threshold values as mentioned above were decided by the experience gathered in the pilot study on fixed and moving dried figs on the conveyor belt. At the end of the thresholding process, most of the dried fig surface areas disappeared in the binary image. Unwanted areas such as normal fig peel, background of the conveyor belt, and some other

defects and diseases were successfully eliminated, and as a result, they were turned into black. Only aflatoxin contaminations remained as red areas in the final image of classification. While the sample moved on the conveyor belt, images of both sides of the fruit were acquired. Evidently, only the aflatoxin contamination remained in the final images. Normal dried fig surfaces, background of the conveyor belt, and some other defects and diseases were not detected. 'Aflatoxin contaminated' and 'Uncontaminated' decisions were given according to the final images of the dried figs.

Healthy and aflatoxin contaminated dried figs were examined graphically in the range of 0-255 color space, thus differences were observed by using color histograms. While the x-axis referred

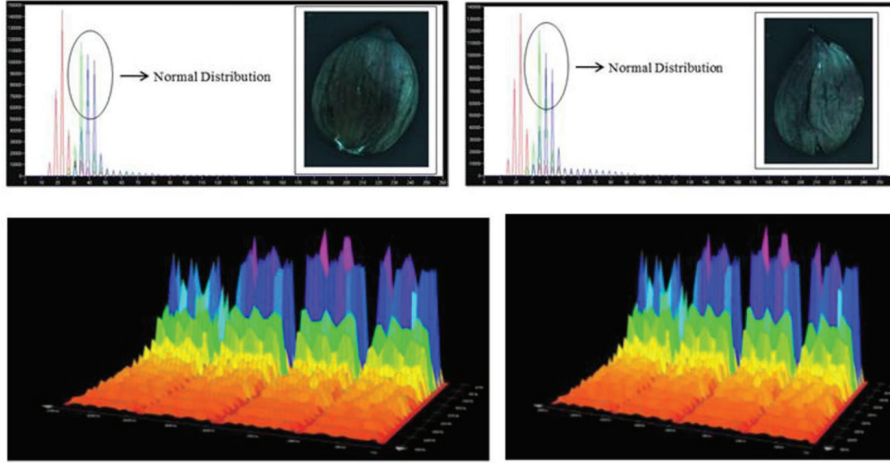


Figure 12- Identification of healthy fig samples on the color space

Şekil 12- Renk uzayında sağlıklı incir örneklerinin saptanması

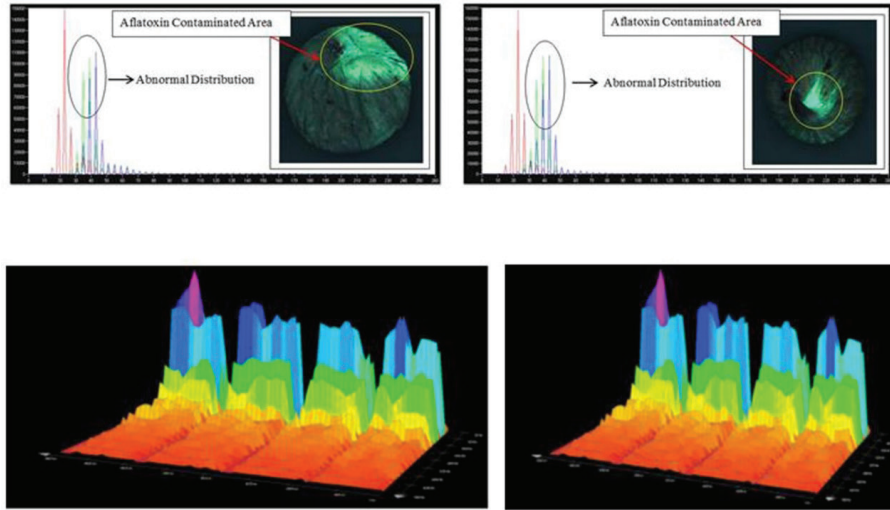


Figure 13- Identification of aflatoxin contaminated fig samples on the color space

Şekil 13- Renk uzayında aflatoksinli incir örneklerinin saptanması

to the color intensity, the y-axis referred to the number of pixels (pixel density) for each chart. The results of the study show that, healthy and aflatoxin contaminated figs have similar characteristic charts among themselves. The graphs obtained (Figure 12 and Figure 13) are similar in structure with the studies of BT (2006) and RPBS (2009).

3.2. System classification efficiency results

The system classification efficiency results are summarized in Table 1 to distinguish between aflatoxin contaminated dried figs and samples without aflatoxin contamination. As seen in the table, 96% of the aflatoxin contaminated figs were accurately classified into the 'Aflatoxin Contaminated' class.

Table 1- System classification efficiency results for dried figs contaminated and uncontaminated with aflatoxin*Çizelge 1- Aflatoksinli ve aflatoksinsiz kuru incirler için sınıflandırma ve sistem etkinliği sonuçları*

<i>Class (Surface condition)</i>	<i>Number</i>	<i>Misclassified</i>	<i>*Identification and separation efficiency (%)</i>	<i>Turnover efficiency (%)</i>	<i>Total system efficiency (%)</i>	<i>Hourly machine capacity (kg h⁻¹)</i>
Contaminated (n=200)	200	8	96	82	80.36	34.56
Uncontaminated (n=200)	200	0	100			
	400	8	98			

*, since the main purpose of the study was about detecting and separating of aflatoxin contaminated dried figs, the conveyor turnover efficiency was omitted for the classification experiments.

8 samples among 200 aflatoxin contaminated dried figs were incorrectly classified. Classifying of the 200 samples in the ‘Uncontaminated’ class was 100%. Identification and separation efficiency was 98% during the test. There were red pixels in the final images after applying real-time image procedures to the aflatoxin contaminated dried figs. Identification and separation efficiency, turnover efficiency, hourly machine capacity and total system efficiency are also listed in Table 1. As listed in Table 1, total system efficiency of the system was calculated as 80.36% by multiplying the identification and the separation efficiencies with the turnover efficiency.

Optimal operating parameters before calculating the turnover efficiency was obtained by determining the different falling heights between belt conveyors and considering the speed combinations of the belts together. According to the results obtained from experimental data, the first belt had to be faster than the second one. Turnover efficiency of the system was calculated as 82% under these conditions. Parameters affecting the dried fig turnover efficiency were, the size of the dried fig belt conveyor contact area, the location of the center of gravity of the dried figs and the sticking effect of the figs (resulting from the natural properties of figs).

According to the operating parameters (different falling heights between belt conveyors, speed combinations of the belts, etc.), hourly machine capacity of the system was calculated as 34.56 kg h⁻¹, which is listed in Table 1.

4. Conclusions

A real-time aflatoxin contaminated dried fig detection and separation system was developed at the wavelength of 365 nm. Dried figs were irradiated with a UV light source in a dark environment and abnormal reflection of aflatoxin contaminated figs was identified using cameras. A special software was created to identify the contaminated products at the time of transferring images to the computer. Aflatoxin contaminated products were photographed by using cameras under the UV light sources, the captured images were transferred to the computer using image processing techniques, and aflatoxin contamination was detected. Finally, two certain decisions-‘Aflatoxin contaminated’ and ‘Uncontaminated’ for dried figs were given for the final images. The average system classification efficiency was 98% for 400 dried figs.

The detection performance could be enhanced by using more cameras. Consequently, fruit surfaces could be scanned completely and inspection of contaminated figs could be achieved successfully in future works. In further investigations, operational efficiency and capacity could be increased by using multiple channels in these systems, instead of feeding the line with a single row. Choosing aflatoxin contaminated figs from the line, where all figs (aflatoxin contaminated and uncontaminated) are moving on the conveyor belt together, could be

another approach by using a special robotic arm and image processing techniques. Besides, the turnover efficiency could be increased through innovations in the turnover unit.

This study will be a model for researchers, who aim to work on similar topics, and it will have a positive effect on system design in many different areas.

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