Journal of Tekirdag Agricultural Faculty
Tekirdağ Ziraat Fakültesi Dergisi

Ocak/January 2021, 18(1)
Başvuru/Received: 15/06/20
Kabul/Accepted: 12/11/20
DOI: 10.33462/jotaf.753185

http://dergipark.gov.tr/jotaf
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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Determination of Colour and Kinetic Parameter Differences Between Aflatoxin Contaminated and Uncontaminated Pistachio Nuts Using Machine Vision

Yapay Görme Sistemi Kullanılarak Aflatoksinli ve Aflatoksinsiz Antep Fıstıkları Arasındaki Renk ve Kinetik Parametre Farklılıklarının Belirlenmesi

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Abstract

Aflatoxins produced by *Aspergillus* species have a great important in the food industry, especially in dried nuts and fruits. Agricultural products are prone to the aflatoxins during the stages like harvesting, drying and storage. Rapid identification of aflatoxin contaminated products is of great interest to the food industry. The food companies start using screening technologies instead of human labour to become more profitable and accurate. Moreover, economical losses and diseases resulting from aflatoxin contamination are a significant problem. The objective of this study was to develop an image processing based aflatoxin contaminated in-shell pistachio nut identification system in order to separate aflatoxin contaminated pistachio nuts from the healthies one. Bright greenish yellow fluorescence (BGYF), which indicates possible aflatoxin contamination, was investigated as a discriminating factor for identification of contaminated pistachio nuts. A total of 100 pistachio nut samples (50 BGYF+ and 50 BGYF-) were evaluated. In the study, imaging algorithms were developed in order to classify the pistachio nut samples as BGYF+ and BGYF-. The colour (L^*, a^* and b^*) and kinetic (chroma, hue angle and browning index) parameters of each pistachio nut sample were analysed and differences between them were determined statistically. Colour and kinetic parameters were also grouped and associated each other by using factor analysis method to simplify the image processing algorithm. Statistically significant differences were found for all colour and kinetic parameters between two groups. According to the factor analysis results; chroma, a^* and browning index values were substantially loaded on Factor 1, while hue angle and b^* were substantially loaded on Factor 2. The remaining variable L^* was substantially loaded on Factor 3. In future studies, an optimized (more effective and convenient) image processing algorithm for developing a new real-time determination and separation system will be enhanced based on the statistical analysis results. The results obtained from this study will form a basis for further investigations.

Keywords: Aflatoxin, Colour and kinetic parameters, Factor analysis, LabVIEW, Pistachio nut

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Atıf/Citation: Ömer Barış ÖZLÜOYMAK, Emin GÜZEL. Determination of Colour and Kinetic Parameter Differences Between Aflatoxin Contaminated and Uncontaminated Pistachio Nuts Using Machine Vision. *Tekirdağ Ziraat Fakültesi Dergisi,* 18 (1), 157-168.

Özet

Aspergillus türleri tarafından üretilen aflatoksinler, gıda endüstrisinde, özellikle kuru fındık ve meyvelerde büyük önem taşımaktadır. Tarım ürünleri hasat, kurutma ve depolama gibi aşamalarda aflatoksinlere daha yatkındır. Aflatoksinli ürünlerin hızlı bir şekilde tanımlanması, gıda endüstrisi için büyük önem taşımaktadır. Gıda endüstrisi, daha karlı ve doğru sonuçlar elde etmek için insan gücü yerine görüntüleme teknolojilerini kullanmaya başladılar. Ayrıca aflatoksin kontaminasyonundan kaynaklanan ekonomik kayıplar ve hastalıklar da önemli bir sorun teşkil etmektedir. Bu çalışmanın amacı, aflatoksinli antep fıstıklarını sağlıklı olanlardan ayırmak için görüntü işleme tabanlı bir aflatoksinli antep fıstığı tanımlama sistemi geliştirmektir. Olası aflatoksin kontaminasyonunu gösteren parlak yeşilimsi sarı floresan (BGYF), kontamine antep fıstıklarının tanımlanması için ayırt edici bir faktör olarak araştırılmıştır. Toplam 100 adet antep fıstığı örneği (50 BGYF+ ve 50 BGYF-) değerlendirilmiştir. Çalışmada, antep fıstığı örneklerini BGYF+ ve BGYF- olarak sınıflandırmak amacıyla görüntüleme algoritmaları geliştirilmiştir. Her bir antep fıstığı örneğinin renk (L^*, a^* ve b^*) ile kinetik (kroma, renk tonu açısı ve kahverengileşme indeksi) parametreleri analiz edilmiş ve aralarındaki farklar istatistiksel olarak belirlenmiştir. Renk ve kinetik parametreler de gruplandırılmış, görüntü işleme algoritmasını basitleştirmek amacıyla faktör analizi yöntemi kullanılarak birbirleriyle ilişkilendirilmiştir. İki grup arasındaki tüm renk ve kinetik parametreler için istatistiksel olarak anlamlı farklılıklar bulunmuştur. Faktör analizi sonuçlarına göre; kroma, a^* ve kahverengileşme indeksi değerleri büyük ölçüde Faktör 1'de yer alırken, renk ton açısı ve b^* değerleri ise Faktör 2'de yer almıştır. Geriye kalan L^* değeri ise Faktör 3'de yer almıştır. Gelecek çalışmalarda, yeni bir eş zamanlı tespit etme ve ayırma sistemi geliştirmek amacıyla optimize edilmiş (daha etkili ve kullanışlı) bir görüntü işleme algoritması, istatistiksel analiz sonuçlarına dayalı olarak geliştirilecektir. Bu çalışmadan elde edilen sonuçlar daha ileri araştırmalar için de bir temel oluşturacaktır.

Anahtar Kelimeler: Aflatoksin, Renk ve Kinetik Parametreler, Faktör Analizi, LabVIEW, Antep fıstığı

1. Introduction

Aflatoxins are a family of closely related secondary metabolites produced by some strains of moulds (i.e., *Aspergillus flavus* and *Aspergillus parasiticus*), which are such highly toxic and carcinogenic compounds (Iamanaka et al., 2007; Lunadei et al., 2013; Hepsag et al., 2014; Kalkan et al., 2014). Aflatoxins consist of a group of approximately 20 related secondary fungal metabolites. But only aflatoxins B_1, B_2, G_1 and G_2 are normally found in foods depending on their fluorescence responses (Iamanaka et al., 2007; Kalkan et al., 2014). B_1 is known as the most carcinogenic and potent genotoxic aflatoxin type for humans (Dichter, 1984; Hepsag et al., 2014).

Three species of Aspergillus: *Aspergillus flavus*, *Aspergillus parasiticus* and *Aspergillus nomius* can occur in a wide range of important agricultural products such as cereals, nuts, spices, figs and dried fruits (Iamanaka et al., 2007). Instantaneous rains, high humidity, and mild temperature may also further the fungal activity. In addition to that, storage is also another phase for mycotoxin production (Ozluoymak and Guzel, 2018). Consuming the aflatoxin at more than the allowed limits may be hazardous to humans and animals (Lizárraga-Paulín et al., 2011; Lunadei et al., 2013).

There are several analytical methods to determine the aflatoxin contamination in foods. Thin-layer chromatography (TLC), high-performance liquid chromatography (HPLC), liquid chromatography-mass spectrometry (LC-MS) and enzyme-linked immunosorbent assays (ELISA) are the most common methods for aflatoxin detection (Lunadei et al., 2013; Kalkan et al., 2014). Although these methodologies are quite accurate, they require skill and equipment, as well as they are time consuming and expensive (Lunadei et al., 2013; Ozluoymak and Guzel, 2018). In recent years, there has been an increase in demand for specific, accurate, simple, and quick methods for the determination of aflatoxins (Nilüfer and Boyacıoğlu, 2002). Gloria (2011) stated that fungal growth can cause some chemical changes in forms or colours of nuts and grains.

As Lunadei et al. (2013) and Kalkan et al. (2014) mentioned that if a food exhibits a bright greenish yellow fluorescence (BGYF) under an ultraviolet light (UV, 365 nm), this indicates that there are aflatoxigenic moulds. Although there is not a 100% relationship between aflatoxin and BGYF, this fluorescence is probably an indicator for kojic acid, a metabolite of *Aspergillus flavus* and *Aspergillus parasiticus* or possibly aflatoxin itself. The relationship between Aspergillus flavus-infection and BGY fluorescence and aflatoxin was first reported in cottonseed by Marsh et al. (1969).

There are several studies about determining the aflatoxin contamination in foods by using the BGY fluorescence under the UV excitation in the literature. Ataş et al. (2012) used hyperspectral imaging to classify aflatoxin contaminated and uncontaminated chili peppers each other by using a compact machine vision system. Özlüoymak (2014) developed and tested a prototype for real-time detection and separation of aflatoxin contaminated dried figs. RGB (Red, Green, Blue) colour space was used for applying the colour threshold method. The system tested by using 400 dried figs separated aflatoxin contaminated dried figs with a success rate of 98%. Güneş et al. (2013) developed a machine vision based non-destructive method for detecting the BGYF figs under UV illumination. Feature extraction was obtained by colour histograms of dried fig surface images. Campbell et al. (2003) developed a real time automated sorter in order to detects and removes aflatoxin contaminated nuts from the processing stream by using discoloration feature of nuts. Pearson (1996) developed a machine vision system in order to separate stained pistachio nuts from the unstained ones. Pearson and Schatzki (1998) used that sorter developed by Pearson (1996) to re-sort colour-sort and hand-sort rejects and to sort mainstream U.S. pistachios. Sorting process was carried out at commercial speeds of up to 163 kg/channel/h.

Pistachio kernels are often eaten as snacks, roasted and salted, and are also used in ice cream and confections such as baklava, helva, lokum and chocolate (Hepsag et al., 2014). McClure and Farsaie (1980), Steiner et al. (1988) and Hadavi (2005) stated that BGY fluorescence under the UV excitation was used as a screening method to detect the aflatoxin in pistachio nuts. Wu and Xu (2019) investigated the utility of multiplexing fiber optic LIFS (Laser Induced Fluorescence Spectroscopy) method in discriminating control and low level of AFB_1 (≤ 50 ppb) contaminated pistachio kernels for quality control of agricultural products. Wu and Xu (2020) used the on-line LIFS system coupled with three detection probes for discriminating non-contaminated and low concentration of AFB_1 contaminated pistachio kernels. Wu et al. (2019) investigated the feasibility of classifying aflatoxin B_1 (AFB_1) contamination in 250 kernels of two pistachio varieties using LIFS.

The aim of this study was to apply an image processing based vision system utilizing an ultraviolet light in order to identify BGYF compounds on the pistachio nuts' surface that is likely associated with aflatoxin contamination. Unlike the previous studies carried out, colour and kinetic parameters of BGYF+ and BGYF- pistachio nuts were compared each other and these parameters belongs to the aflatoxin contaminated pistachio nuts were classified in order to simplify the image processing algorithm by using statistical analysis methods. The image processing load of microprocessors could be reduced by using more effective and less image processing parameters. As stated in the literature, the most commonly used parameter for classification and separation processes is the colour information of the agricultural products. Image processing time should be reduced by improving the processing time and speed of the artificial vision systems.

2. Materials and Methods

2.1. Sampling of pistachio nut samples

In-shell pistachio nut samples were obtained from an exporting company in Gaziantep, Turkey. The BGYF+ and BGYF- pistachio nut samples were manually separated by human inspectors in the company. Randomly chosen samples determined as BGYF+ were analysed and confirmed by the company. While 50 BGYF+ pistachio nut samples were randomly selected from the fluorescent group, 50 BGYF- pistachio nut samples were randomly chosen from the non-fluorescent group. Medical gloves were worn during the experimental studies.

2.2. The Imaging System

The imaging system for detecting aflatoxin contamination on pistachio nuts was set up in a darkened laboratory under the UV lighting (Figure 1).

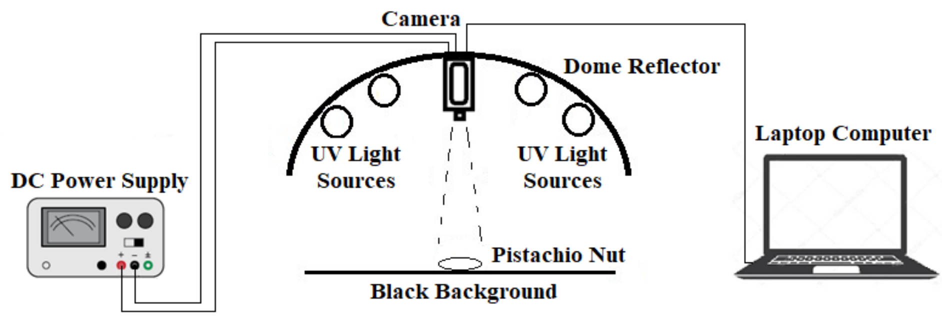

Figure 1. Schematic drawing of the imaging system

The lighting unit was provided by four 36W UV black-light lamps (Philips, TL-D/08). In order to apply uniform reflectance illumination, an aluminium dome reflector was placed above the lighting unit. A 0.3 megapixel GigE machine vision camera (AVT Mako G-030 C) equipped with a 9 mm lens (Fujinon HF9HA-1B) was used to capture the pistachio nut images. The camera, which has a 1/3” CMOS sensor, runs 309 frames per second at full resolution (644 (H) × 484 (V) pixels). It was energized by using a DC power supply (Pacific, 2305D+). A laptop computer (Acer, Aspire E15) with 4 GB RAM and an Intel Core i5-5200U CPU was used for the imaging system software. The software was developed on the LabVIEW (National Instruments Corporation, Austin-Texas-USA) programming language and the Vision Builder for Automated Inspection (National Instruments Corporation, Austin-Texas-USA). The working distance (the distance between the lens and the top of the sample being observed) was 70 mm and the pistachio nut samples were manually placed in the imaging area. The images were perfectly acquired by using a black background.

2.3. Method

All pistachio nut samples were divided into two groups as fluorescent and non-fluorescent under the 365 nm UV illumination. Aflatoxins, which are invisible in daylight, on the contaminated pistachio nuts radiated bright greenish yellow fluorescence (BGYF) by absorbing the UV light and become visible. 50 BGYF+ and 50 BGYF- pistachio nuts were selected from the fluorescent and non-fluorescent groups, respectively. While aflatoxin level could not be determined for BGYF+ pistachio nut samples, it was determined whether the pistachio nut sample was only aflatoxin contaminated or not. Since the fluorescent sensitivity of the human differs from person to person, machine vision based systems are preferred for such determination and separation systems.

2.3.1. Image Processing Method

The use of BGYF identification criterion on aflatoxin contaminated pistachio nuts was well known as a discrimination factor. The presence of aflatoxin could be determined within the ability of the image processing program to determine the color pixels. The RGB colour model is an additive colour model in which red, green and blue light are added together at different intensities to produce different colours. Since the RGB colour model is device-dependent and could be detect or reproduce differently by different devices, the CIE $L^*a^*b^*$ colour scale, which is approximately uniform colour scale, was preferred at the image processing process. As Sharifian et al. (2013) mentioned that the $L^*a^*b^*$ values are often used in food research studies because of uniform distribution of colours and as $L^*a^*b^*$ units are very close to human perception of colour. The $L^*a^*b^*$ colour space consists of a luminance or lightness component (L^* value, ranging from 0 to 100), along with two chromatic components (ranging from −120 to +120): the a^* component (from green to red) and the b^* component (from blue to yellow).

In this study; a machine vision based non-destructive method was proposed for detecting the BGYF pistachio nuts under the UV illumination by using the CIE $L^*a^*b^*$ colour scale to evaluate the colour changes of pistachio nuts by image analysis. Not only L^*, a^* and b^* values were compared but also the kinetic parameters for the colour change were determined using the total colour change parameter, chroma, hue angle and browning index for discriminating aflatoxin contaminated pistachio nuts from the healthies one.

In order to obtain the RGB pixel values separately, the captured pistachio nut sample images were transferred to the computer and segmented into red (R), green (G) and blue (B) components by selecting the region of interest (ROI). Colour values in L^*, a^* and b^* units were analysed after the conversion process from the RGB colour space into the $L^*a^*b^*$ units.

Firstly, RGB values were converted to the XYZ colour space. Secondly, XYZ values were converted to the CIE $L^*a^*b^*$ colour space. L^*, a^*, and b^* components were calculated using relations as given below (Erdem et al., 2018):

$$L^* = 116\left(\sqrt[3]{\frac{Y}{Y_0}}\right) - 16 \quad \text{Eq. (1)}$$

$$a^* = 500\left[\sqrt[3]{\frac{X}{X_0}} - \sqrt[3]{\frac{Y}{Y_0}}\right] \quad \text{Eq. (2)}$$

$$b^* = 200\left[\sqrt[3]{\frac{Y}{Y_0}} - -\sqrt[3]{\frac{Z}{Z_0}}\right] \quad \text{Eq. (3)}$$

where (X_0, Y_0, Z_0) are X, Y, Z values for standard white respectively. The value of X, Y and Z is computed using a linear transformation from RGB coordinates as follows (Erdem et al., 2018):

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 0.607 & 0.174 & 0.200 \\ 0.299 & 0.587 & 0.114 \\ 0.000 & 0.066 & 1.116 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \quad \text{Eq. (4)}$$

Colour measurement as RGB of the selected region of interest belonging to the BGYF+ or BGYF- pistachio nuts was carried out by using the Vision Builder for Automated Inspection. Then, obtained RGB data were assigned to the variables, separately. At the end of the process, these RGB variables were taken by developed LabVIEW programming software and converted to the CIE $L^*a^*b^*$ colour space.

Visible fluorescent stain of BGYF+ pistachio nut sample images and the pistachio nut sample images without fluorescent stains determined as BGYF- acquired under 365 nm illumination were given in Figure 2 (a) and (b), respectively.

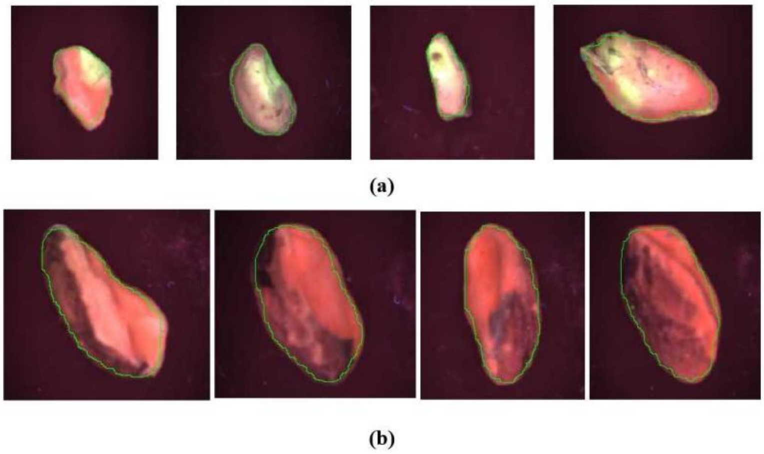

Figure 2. (a) Visible fluorescent stain of BGYF+ pistachio nut sample images; (b) BGYF- pistachio nut sample images

2.3.2. Kinetics of Colour Changes

The colour discrimination between the fluorescent and non-fluorescent pistachio nut samples was described by using chroma, hue angle and browning index (BI) calculated from the L^*, a^* and b^* values.

The chroma or saturation index is proportional to its intensity and indicates colour saturation. While the hue angle characterizes colour in food products, the BI is used for determining the purity of brown colour. All these parameters were calculated from the following equations (Sharifian et al., 2013; Erdem et al., 2018):

$$Chroma = \sqrt{(a^{*2} + b^{*2})} \quad \text{Eq. (5)}$$

$$Hue\ Angle = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad \text{Eq. (6)}$$

$$BI = \frac{[100(x - 0.31)]}{0.17}, \qquad x = \frac{(a^* + 1.75L^*)}{(5.645L^* + a^* - 3.012b^*)} \quad \text{Eq. (7)}$$

where L^*, a^* and b^* values correspond to colour values of pistachio nuts. Each test was replicated three times and then averaged.

2.3.3. Statistical Analysis of Colour Parameters

The colour parameters of BGYF+ and BGYF- pistachio nuts were statistically evaluated. L^*, a^*, b^*, chroma, hue angle (radian) and browning index (BI) values of BGYF+ and BGYF- pistachio nuts were compared in order to determine the significance level between the groups. The t-test was used according to the results of the normality tests. As known, t-tests are a type of hypothesis test that allows to compare means.

50 BGYF+ and 50 BGYF- pistachio nut samples were used in the statistical analysis tests. As the number of samples was greater than 30 for all groups, the significance value of the Kolmogrov-Smirnov normality test was considered.

In order to determine which colour parameters are close to each other and find the clustering of colour parameters, factor analysis technique in SPSS was used to reduce a large number of variables into fewer numbers of factors. Thus, the colour parameters were being accurately classified.

3. Results and Discussion

3.1. Colour and Kinetic Parameters Results

The results of colour parameters (L^*, a^* and b^* values) and kinetic parameters (chroma, hue angle (radian) and browning index (BI) calculated by using L^*, a^* and b^* values) of BGYF+ and BGYF- pistachio nuts were presented in Figure 3 and Figure 4, respectively. The colour parameters of aflatoxin contaminated areas had brighter colour than the uncontaminated pistachio nut surface colour parameters (because of BGYF) under the UV illumination as shown in Figure 3. L^* value increased, and a^* and b^* values decreased on average, when the BGYF- pistachio nuts were compared with the BGYF+ pistachio nuts in terms of colour parameters.

While chroma and BI values decreased, hue angle (radian) value increased on average when the kinetic parameters of BGYF+ and BGYF- pistachio nut samples compared as shown in Figure 4.

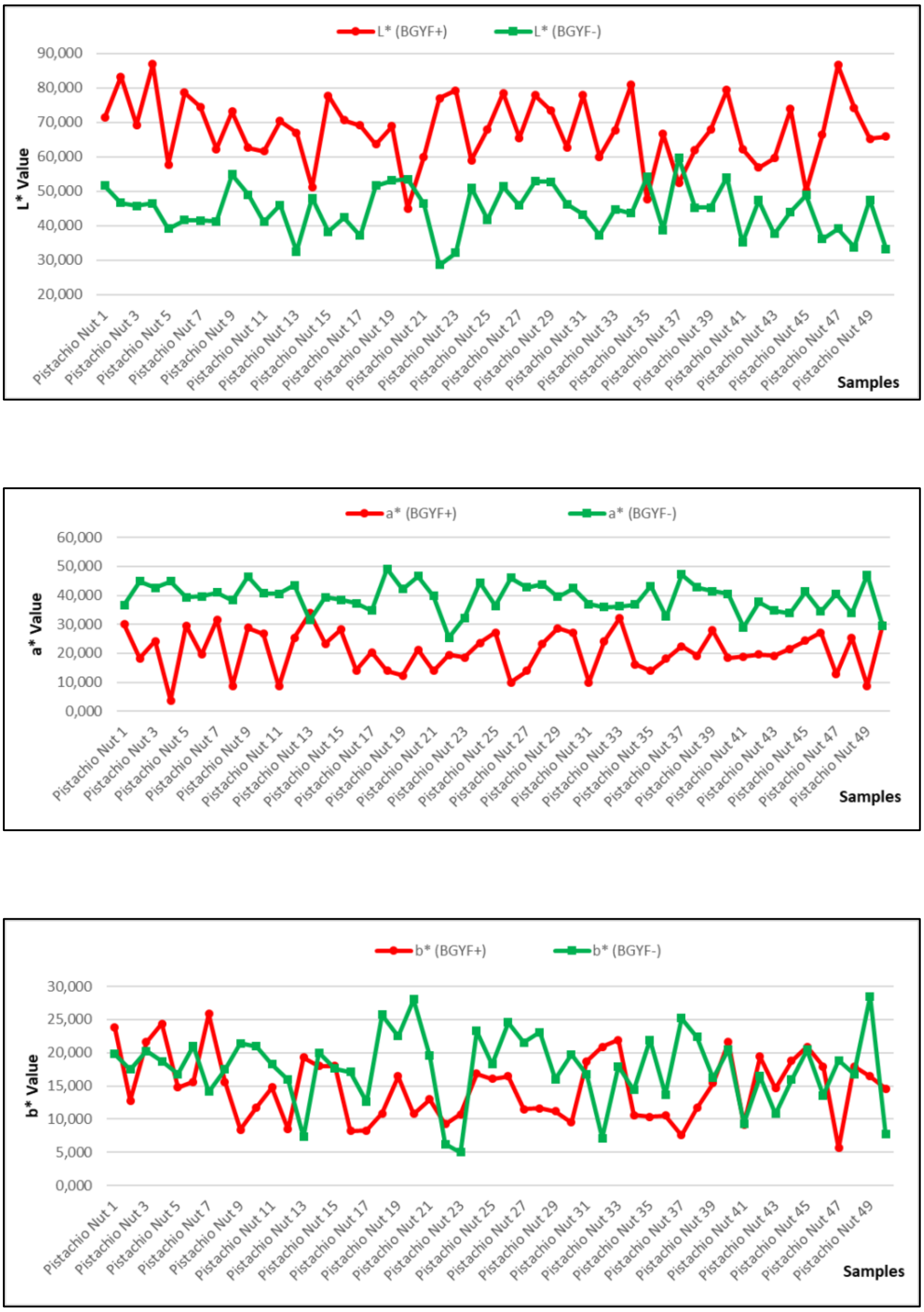

Figure 3. Changes in the colour parameters of BGYF+ and BGYF- pistachio nuts

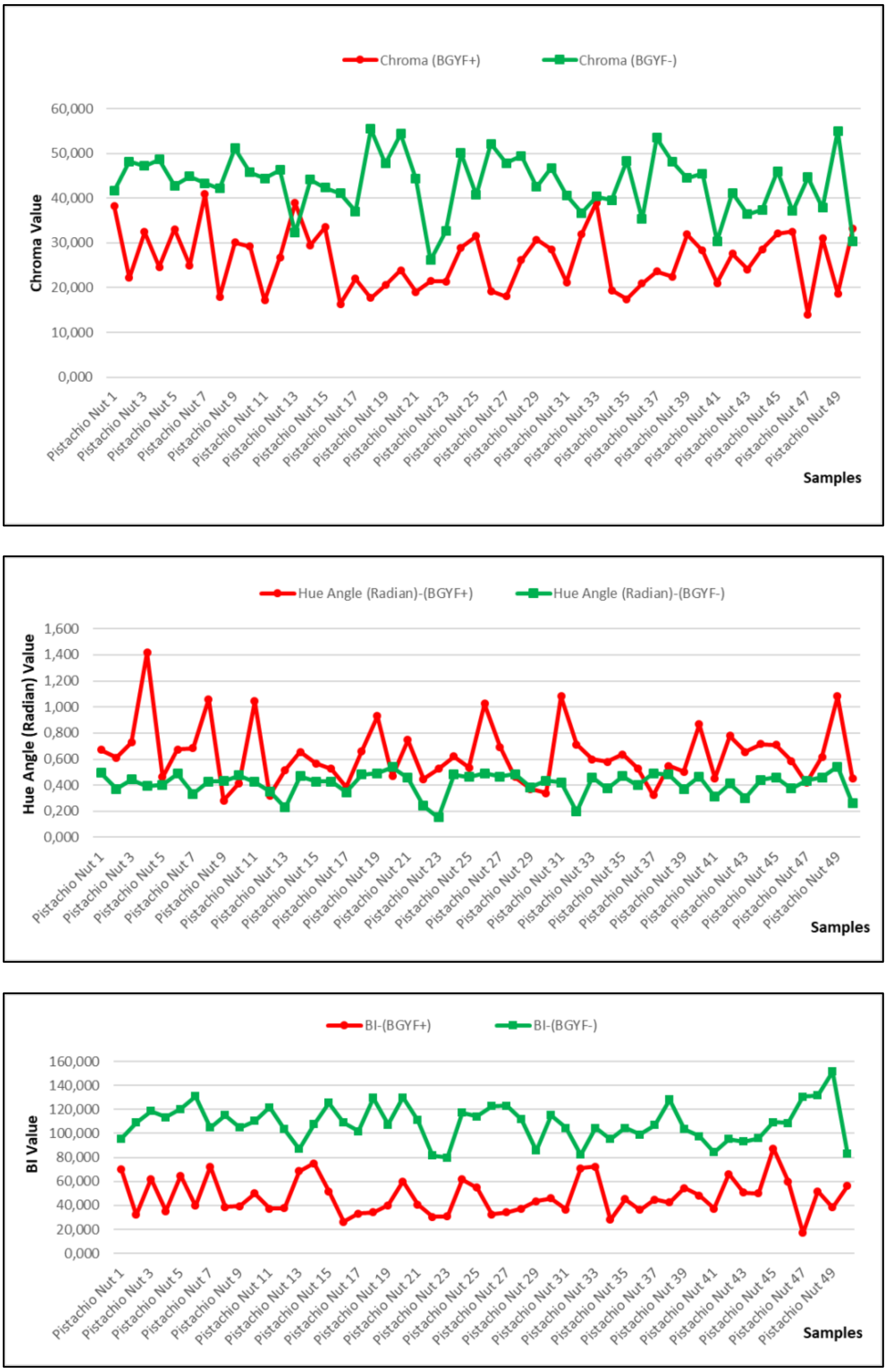

Figure 4. Changes in the kinetic parameters of BGYF+ and BGYF- pistachio nuts

3.2. Statistical Analysis Results

The Kolmogorov-Smirnov normality test was examined because all variables were normally distributed. 50 pistachio nut samples for all groups were assessed in the normality tests. For this reason, the Kolmogorov-Smirnov

Test was used as the numerical means of assessing normality. The data were distributed normally for L^*, a^*, b^*, chroma, hue angle and BI because sig. values were greater than 0.05 according to the Kolmogorov-Smirnov Test.

A t-test is a type of inferential statistic used to determine if there is a significant difference between the means of two groups. If the data has normal distribution, t-test is used for determining the difference and significance level. The L^*, a^*, b^*, chroma, hue angle and BI values of BGYF+ and BGYF- pistachio nut samples were evaluated by using the t-test. Since the results of sig. (2-tailed) for uniform and non-uniform distributions were less than 0.05, significant differences were found between the mean of the groups as shown in Table 1. As a result, there were statistically significant differences between the two groups for all colour parameters of BGYF+ and BGYF- pistachio nut samples.

Table 1. T- test results for BGYF+ and BGYF- pistachio nuts

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**Lower**	**Upper**
L^*	E. v. a.	4.297	.041	13.764	98	**.000**	23.36986	1.69795	20.00034	26.73938
	E. v. not a.			13.764	88.616	**.000**	23.36986	1.69795	19.99587	26.74385
a^*	E. v. a.	6.674	.011	-14.779	98	**.000**	-18.54574	1.25483	-21.03591	-16.05557
	E. v. not a.			-14.779	88.934	**.000**	-18.54574	1.25483	-21.03909	-16.05239
b^*	E. v. a.	.005	.943	-2.821	98	**.006**	-2.92236	1.03603	-4.97834	-.86638
	E. v. not a.			-2.821	97.212	**.006**	-2.92236	1.03603	-4.97854	-.86618
Chroma	E. v. a.	.462	.498	-12.883	98	**.000**	-17.16134	1.33206	-19.80477	-14.51791
	E. v. not a.			-12.883	97.993	**.000**	-17.16134	1.33206	-19.80477	-14.51791
Hue_Angle	E. v. a.	20.646	.000	6.312	98	**.000**	.22100	.03501	.15152	.29048
	E. v. not a.			6.312	62.190	**.000**	.22100	.03501	.15102	.29098
BI	E. v. a.	.113	.737	-19.869	98	**.000**	-60.90594	3.06534	-66.98900	-54.82288
	E. v. not a.			-19.869	97.959	**.000**	-60.90594	3.06534	-66.98904	-54.82284

E. v. a.: Equal variances assumed
E. v. not a.: Equal variances not assumed

Three methods, which are creating the correlation matrix, Bartlett's test and Kaiser-Meyer-Olkin (KMO) test, were used to evaluate whether the data set for BGYF+ pistachio nuts is suitable for factor analysis. Since the result of the KMO test was greater than 50% and the sig. value (0.000) was less than 0.05 according to the Barlett's test, there were high correlation between variables and the data set was suitable for factor analysis. The obtained results by using SPSS statistical analysis software for BGYF+ pistachio nuts were shown in Table 2. As mentioned before, the aim of the factor analysis is the orderly simplification of a number of interrelated measures. With the help of that analysis, colour parameters and kinetic parameters were grouped and associated each other.

Table 2. Factor analysis test results for BGYF+ pistachio nuts

Component Matrix[a]

	Component		
	1	2	3
Chroma	.955	.045	.270
BI	.931	.192	-.283
a^*	.864	-.439	.235
Hue_Angle	-.261	.952	-.126
b^*	.583	.802	.101
L^*	-.312	.198	.927

Extraction Method: Principal Component Analysis.

[a] 3 components extracted.

Rotated Component Matrix[a]

	Component		
	1	2	3
Chroma	**.993**	.018	.019
a^*	**.884**	-.459	-.046
BI	**.832**	.228	-.489
Hue_Angle	-.260	**.959**	.054
b^*	.609	**.788**	.039
L^*	-.060	.088	**.992**

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

[a] Rotation converged in 4 iterations.

Table 2 shows the loadings of the six variables for BGYF+ pistachio nuts on the three factors extracted. It means that the higher the absolute value of the loading, the more the factor contributes to the variable. The idea of rotation does not actually change anything but makes the interpretation of the analysis easier. It can be seen that chroma, a^* and BI values were substantially loaded on Factor (Component) 1, while hue angle and b^* were substantially loaded on Factor (Component) 2. The remaining variable L^* was substantially loaded on Factor (Component) 3.

These factors can be used as variables for further studies like image processing based aflatoxin contaminated pistachio nut separating machines. Especially, few parameters (colour and kinetic) will positively affect the system performance and programming speed.

4. Conclusions

Vision systems are used in food industry for sorting and quality inspection because of being easy, objective, representative, precise and inexpensive. These systems use image processing techniques to measure and analyse colour evolution in the food industry.

An aflatoxin contaminated pistachio nut detection system combined with the image processing was developed at the wavelength of 365 nm. An UV light source irradiated the pistachio nuts in a darkened laboratory and contaminated pistachio nuts exhibited bright-greenish yellow fluorescence. The pistachio nut images were captured by using a camera and LabVIEW based software was developed for determining the colour and kinetic parameters of both BGYF+ and BGYF- pistachio nuts. Monitoring colour changes of pistachio nuts by using image processing simplified the separation process in comparison with the manual identification. Changes of colour and kinetic parameters between in-shell pistachio nut samples with BGYF+ and BGYF- were investigated. Aflatoxin contamination caused the colour of contaminated pistachio nut to be lighter than the healthies one.

In further investigations, a separation machine could be developed to separate the BGYF+ and BGYF- pistachio nuts according to their colour and kinetic parameters. Moreover, new statistical approach (factor analysis) was offered to simplify and accelerate the image processing software performance of the separation machine.

This study will be a new approach for researchers, who work on separation system design, and it will also have a positive effect in terms of simplifying the separation process for dried fruits.

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