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Assessing the Level of Adulteration in Firik Bulgur Mixed with Regular Bulgur by Using a Color Meter: A Preliminary Study

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Abstract

Firik bulgur is produced by a different method than regular bulgur and is more nutritious but it is three to four times more expensive than regular bulgur. Adulteration is common by mixing regular bulgur to firik bulgur. It is impossible to determine the adulteration level by human eye. In this work, the possibility of detecting the ratio of regular bulgur in the adulterated (mixed) firik bulgur was studied. Two different data sets (DS1 and DS2) were prepared with two different brands of firik bulgur mixed with regular bulgur (mix ratio: from 0 to 100% with increments of 2.5%). Colors of the mixture samples were quantified by using a color meter by two color models (L*a*b* and L*C*h). Correlation and regression analyses were applied. Half of the data (n=41) was used for calibration and the other half (n=41) for validation in the regression analysis. It was found that the regular bulgur ratio in the mixture could be estimated from color data. A slightly better prediction performance was obtained in the DS2 data set (RMSEP=12%; R2=0.83) compared to the DS1 data set (RMSEP=19%; R2=0.57). In sum, a chromameter offers promising results to estimate the ratio of regular bulgur in the adulterated firik bulgur with reasonable accuracy (R²=0.83).

Keywords: Bulgur, food fraud, color meter, correlation, regression

1.INTRODUCTION

Bulgur plays an important role in the traditional human diet due to its fiber, vitamin and mineral contents (Donmez et al., 2004). It is a very common product in Türkiye, the Middle East, Central Asia, Balkans, and North Africa (Dorra et al. 2022; Pekkirisci, 2022). It is also consumed in other regions and countries (the USA, Europe, Australia, Japan, China, and Russia) (Yousif et al., 2018). Bulgur is produced from wheat, usually from durum wheat but bread wheat can also be used (Donmez et al., 2004; WFP, 2021). The top five wheat producer countries were China, India, Russia, the USA and France in 2021 as Türkiye ranked 12th with a production of about 17.7 million tons in the same year (FAOSTAT, 2021). Around 1.2 million tons of bulgur is annually produced in Türkiye in about 500 bulgur factories (EnSonHaber, 2020). The main bulgur producer provinces are Gaziantep, Karaman and Corum as there are many large and small factories in other provinces (Donmez et al., 2004). Türkiye is the largest bulgur producer and exporter in the world (Koksal and Cetiner, 2015; Giambanelli et al., 2020).

Bulgur provides many health benefits to humans with advantages of long shelf life, being inexpensive, and easy preparation (Bayram, 2013; Shah et al., 2022). It helps keep blood sugar under control due to its high fiber content and low glycemic index. Bulgur has a higher content of protein, fiber, unsaturated fatty acids, folate, vitamins (B1, B2, E) and minerals (Ca, Fe, K, Mg, Zn, P, Cr) and less carbohydrate level compared to rice so it is a healthier food product (Caba et al., 2012;

Carsanba et al., 2017; Yilmaz and Yildirim, 2020; Rafinera, 2022; Snyder, 2023).

There are two types of bulgur in Türkiye that differ significantly from each other based on their production method: "regular bulgur" and "firik bulgur". The first one, regular bulgur, is produced by boiling wheats of yellow-colored, low moisture, and fully ripened while firik bulgur is produced by roasting unripen, moist, and green colored wheats with their stems, ears, and husks together. This heat processing provides a significant advantage to bulgur such as resistance against mold contamination and insect damage; thus, bulgur is a more stable product than wheat which has a respiration activity and active enzyme in the kernel (Singh et al. 2013).

Regular bulgurs are produced and marketed in two types in terms of grain size; "bulgur for pilaf" (pilavlik bulgur) has larger grain size and is used to prepare traditional "bulgur pilaf". In contrast, "bulgur for kofte" (köftelik bulgur) has smaller grain size and is utilized to prepare traditional foods such as "köfte", "kisir" and it is also used in some soups.

Production of regular bulgur from wheat takes place in nine stages: harvesting fully ripened wheat, cleaning/washing, soaking, boiling, drying, sieving/sorting, peeling, crushing/screening, and (Aksehir packaging/storage Grup, 2014). Conversely, firik bulgur is produced with five harvesting wheat, processes: unripe burning/smoking/roasting the wheats with ears, stems and husks together, separating the grains, drying, and packaging/storage (GTB, 2017; Yilmaz and Yildirim, 2020). Hence, there are some significant differences between regular bulgur and firik bulgur which mainly comes from two main factors: the degree of ripening of wheats used as raw material and the applied heat treatment method. While regular bulgur is obtained by boiling fully ripened and yellowish wheat, firik bulgur is obtained by roasting immature greenish wheat in ears with its stems and husks. Firik bulgur has a greenish color since the wheats are harvested before fully ripining and has a smoked aroma as a result of roasting. Thus, the cooking method considerably affects the aroma and nutritional properties of bulgur (Tekin et al., 2022)

Some researchers compared the nutritional values of firik bulgur, regular bulgur and rice. Protein, total fiber, B1 (thiamine), B2 (riboflavin) and vitamin E (α -tocopherol) contents and mineral elements (Ca, Fe, K, Mg, Zn, P) of firik bulgur were reported to be higher than regular bulgur and rice (Carsanba et al., 2017; Yilmaz and Yildirim, 2020). Also, it has a good source of lutein (antioxidant) and fructooligosaccharides with a lower glycemic index compared to regular bulgur and rice (Yilmaz and Yildirim, 2020).

Research studies have been conducted on regular bulgur products regarding the effects of various cooking, drying and milling methods (Acer, 2004; Savas, 2010; Evlice and Ozkaya, 2020; Goksu et al., 2022; Baumgartner et al., 2023; Rasheed et al., 2023), conformity of its quality to food standards (Can et al., 2014), availability of mycotoxins such as aflatoxin, ochratoxin, etc. (Tayfur et al., 1992; Oguz et al., 2011), effects of different raw materials such as various wheat cultivars and triticale (a hybrid of wheat and rye) (Ozbas and Koksal, 2003; Evlice and Ozkaya, 2020; Cetinkaya-Turkey and Gulbaz, 2022), and the evaluation of wastewater and energy consumption during bulgur production (Balci and Bayram, 2020). There have been lower number of studies on firik bulgur compared to regular bulgur such as the availability of mycotoxins such as aflatoxin, ochratoxin (Kadioglu, 2018), its nutritional properties (Carsanba et al., 2017; Yilmaz and Yildirim (2020), and its production and inspection methods (GTB, 2017)

Food adulteration or food fraud is the production of foods in violation of the permitted specifications causing economic and health-related problems (Bannor et al., 2023). Food products are usually adulterated by adding lower quality and cheaper substances similar to the food itself to increase its amount and obtain a cheaper but lower quality

product. For instance, adding pea powder to pistachio powder, mixing carob powder to ground coffee, butter made of vegetable-based oils with flavors and additives, labeling a non-organic product as an organic product, adding regular bulgur to firik bulgur, and mixing artificial dyes to spices, etc. (Keskin et al., 2021). Food authentication is usually carried out by laboratory chemical analyses; however, these methods require high amount of time, labor, cost and chemical substances. Hence, studies have been out on non-destructive and measurement methods including digital cameras, infrared reflectance spectroscopy, spectroscopy, e-nose, chromameter, etc. to determine adulteration in a short time with less labor and expense (Aslam et al., 2023).

Firik bulgur is more nutritious than regular bulgur but its price is 3-4 times more expensive than regular bulgur. For this reason, adulteration is common by mixing regular bulgur to firik bulgur. It is not possible for the human eye to detect the fraud in firik bulgur. Standard chemical analyses can be used to detect adulteration in firik bulgur. However, these methods have some drawbacks such as time-consuming, sample preparation, consumption chemical of compounds, consumption of energy, risking the health of lab staff, labor requirement and high cost. No study was found on the determination of fraud in firik bulgur before. The aim of this study was to investigate the possibility of fast, non-destructive and low-cost detection of adulteration in firik bulgur in the form of mixing it with regular bulgur by employing a hand-held chromameter.

2. MATERIALS AND METHOD

2.1. Bulgur samples

Regular bulgur and firik bulgur samples were purchased from local and national chain markets in packages of around 1 kg in February 2022. Two different firik bulgur brands (FB1 and FB2) (Table 1) were obtained. As of the regular bulgur (RB) samples, eight different brands were procured similar to firik bulgur samples in terms of grain size and color: RB1 through RB8 (Figures 1 and 2, Table 1).

2.2. Chromameter

Color values of all regular and firik bulgur samples were measured with a hand-held colorimeter (Minolta CR400). Two different color models (CIE L*a*b and L*C*h) were employed in the study. The meanings of each color parameter in these models are explained below (Keskin et al., 2017):

L*: Color brightness (O: black, 100: white)

a*: Redness-greenness value (-60: green, +60: red)

b*: Yellowness- blueness (-60: blue, +60: yellow)

C*: Color chroma (O to 60)

h: Color hue angle (0°: red, 90°: yellow, 180°: green, 270°: blue)

In order to find the most similar regular bulgur brand to each of the two firik bulgur brands, their color values were obtained and their color differences were calculated. The following equations were used to calculate the differences in color parameters (ΔL^* , Δa^* , Δb^* , ΔC^* , Δh) and the total color difference values (ΔE^*_1 , ΔE^*_2) of the samples (Keskin et al., 2017):

$$\Delta a^* = a^*_1 - a^*_2$$
 $\Delta b^* = b^*_1 - b^*_2$
 $\Delta C^* = C^*_1 - C^*_2$
 $\Delta h = h_1 - h_2$

 $\Delta L^* = L^*_1 - L^*_2$

$$\Delta E^*_1 = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5}$$

 $\Delta E_2^* = [(\Delta L^*)^2 + (\Delta C^*)^2 + (\Delta h)^2]^{0.5}$



Figure 1 Samples of two firik bulgurs and eight regular bulgurs used in the study (petri dish diameter is about 9 cm)



Figure 2 Samples of two firik bulgurs (left) and eight regular bulgurs (right) used in the study (petri dish diameter is about 9 cm)

Table 1. Brands of the two firik bulgurs (FB) and eight regular bulgurs (NB) and the corresponding acronyms used in the study

Bulgur types	Bulgur brand names	Acronyms
Firik bulgurs (FB)	Migros firik bulgur	FB1
	Ekmekci firik bulgur	FB2
	Tarim Kredi Pilavlik	RB1
	Kapadokya Siyez	RB2
Regular bulgurs (RB)	Torku Catalhoyuk Pilavlik	RB3
	Duru Basbasi Pilavlik	RB4
	Duru Pilavlik	RB5
	Yoremce Pilavlik	RB6
	Ekmekci Dovme Esmer	RB7
	Anadolu Mutfagi Esmer Pilavlik	RB8

2.3. Bulgur mixtures and adulteration levels

Color values of all bulgur samples from different brands were measured in order to determine the regular bulgur (from the eight different brands) which most closely resembles to the two different brands of firik bulgur in terms of appearance and color. For this purpose, L*, a*, b*, C* and h color values were measured and recorded by taking three samples from each firik and regular bulgurs. The mean and standard deviation values of these three measurements and the color difference values (ΔE_1 , ΔE_2) were calculated in spreadsheet program.

The regular bulgur brand which was most similar to each of the two firik bulgur was determined according to the lowest color difference values $(\Delta E_1, \Delta E_2)$. Hence, it was determined that the regular bulgur, which is most similar in color to FB1 brand firik bulgur, was determined as "RB1" brand regular bulgur (ΔE_1 =4.5) (Table 2). Similarly, it was observed that the regular bulgur, which was most similar to FB2 brand firik bulgur, was "RB3" brand regular bulgur (ΔE_1 =6.2) (Table 3). After this finding, bulgur mixture samples were prepared by mixing firik bulgur and regular bulgur in "certain proportions of firik bulgur in the mixture" (from O to 100% with an increment of 2.5%). Mixture samples were prepared as a total of 40 g each (regular bulgur + firik bulgur). The masses of regular and firik bulgur samples were quantified by using a digital precision balance (Sartorius TE3102S, Germany, accuracy: 0.01 g). For each brand of firik bulgur (FB1 and FB2), mixtures were prepared from O to 100% ratio of firik bulgur with an increment of 2.5% (Table 4). Two separate samples were prepared for each mixing ratio yielding a total of 82 (41x2) samples (Table 4). In this way, two different data sets (DS1 and DS2) for the two different brand firik bulgurs were obtained each of which contained a total of 82 samples (Table 5). The total number of samples was 164 in the two data sets.

2.4. Color data of the bulgur mixture samples

The color values (L*, a*, b*, C*, and h) of the bulgur mixtures obtained with two different brands of firik bulgur (FB1 and FB2) and regular bulgur (RB1 and RB3) similar in color (Figure 3) were measured in the laboratory and recorded in spreadsheet program. Tha data were collected and analyzed in March and April 2022.

2.5. Data analysis

Means, standard deviations and correlation coefficients between the mixture ratios and color data were calculated in spreadsheet program (Microsoft Excel, Microsoft Office 2016). Partial least squares regression (PLSR) method was used for the regression analysis to predict the mixture ratios from the color data in UnScrambler software (v.9.7; Camo; Norway). In the regression analysis, there are several methods for model validation including leverage correction, cross validation and the use of separate test set (Esbensen 2009; Keskin et al., 2013). Among these, the most realistic method is the use of a separate test set while the simplest one is leverage correction method (Esbensen, 2009). Hence, in the current study, half of the samples (n=41) were used for model development (calibration) and the remaining half (n=41) were used as the validation data set. In the data analysis, the estimation error was determined by the RMSEP value (Root mean square error of prediction) calculated with the following equation:

RMSEP= $[(\sum (y_m - y_p)^2) / n]^{0.5}$

where:

 y_m = Measured value,

 y_p = Predicted value,

n = Number of data.

Table 2. Color data (L^* , a^* , b^* , C, and h) and color difference values (ΔE_1 and ΔE_2) of the FB1 firik bulgur and eight regular bulgur samples to determine the most similar regular bulgur to the FB1 firik bulgur

Bulgur type	Bulgur brand	L	a*	b*	С	h	$\Delta \mathbf{E_1}$	$\Delta \mathbf{E_2}$
Firik bulgur	FB1	50.35	0.81	20.68	20.70	87.79	-	-
	RB1	51.93	1.16	24.91	24.94	87.29	4.5	4.5
	RB2	46.72	5.66	13.99	15.11	67.94	9.0	20.9
	RB3	55.36	3.21	22.26	22.50	81.77	5.8	8.0
Regular bulgurs	RB4	57.43	0.84	22.28	22.31	87.78	7.3	7.3
	RB5	57.36	1.10	23.19	23.22	87.26	7.4	7.5
	RB6	52.91	0.23	28.83	28.84	89.50	8.6	8.7
	RB7	50.98	5.99	16.91	17.95	70.55	6.4	17.5
	RB8	41.68	5.85	14.46	15.60	67.98	11.8	22.2

Table 3. Color data (L^* , a^* , b^* , C, and h) and color difference values (ΔE_1 and ΔE_2) of the FB2 firik bulgur and eight regular bulgur samples to determine the most similar regular bulgur to the FB2 firik bulgur

Bulgur type	Bulgur brand	L	a*	b*	С	h	$\Delta \mathbf{E_1}$	ΔE_2
Firik bulgur	FB2	52.47	-0.79	18.43	18.45	92.47	-	-
	RB1	51.93	1.16	24.91	24.94	87.29	6.8	8.3
	RB2	46.72	5.66	13.99	15.11	67.94	9.7	25.4
	RB3	55.36	3.21	22.26	22.50	81.77	6.2	11.8
Regular bulgurs	RB4	57.43	0.84	22.28	22.31	87.78	6.5	7.8
	RB5	57.36	1.10	23.19	23.22	87.26	7.1	8.6
	RB6	52.91	0.23	28.83	28.84	89.50	10.5	10.8
	RB7	50.98	5.99	16.91	17.95	70.55	7.1	22.0
	RB8	41.68	5.85	14.46	15.60	67.98	13.3	26.9

Table 4. Mixture ratios of firik bulgur and regular bulgur used in the study

	Firik	Regular	Firik bulgur ratio	Number of
Sample number	bulgur (g)	bulgur (g)	(%)	samples
1	40	0	0.0	2
2	39	1	2.5	2
3	38	2	5.0	2
4	37	3	7.5	2
5	36	4	10.0	2
6	35	5	12.5	2
7	34	6	15.0	2
8	33	7	17.5	2
9	32	8	20.0	2
10	31	9	22.5	2
11	30	10	25.0	2
12	29	11	27.5	2
13	28	12	30.0	2
14	27	13	32.5	2
15	26	14	35.0	2
16	25	15	37.5	2
17	24	16	40.0	2
18	23	17	42.5	2
19	22	18	45.0	2
20	21	19	47.5	2
21	20	20	50.0	2
22	19	21	52.5	2
23	18	22	55.0	2
24	17	23	57.5	2
25	16	24	60.0	2
26	15	25	62.5	2
27	14	26	65.0	2
28	13	27	67.5	2
29	12	28	70.0	2
30	11	29	72.5	2
31	10	30	75.0	2
32	9	31	77.5	2
33	8	32	80.0	2
34	7	33	82.5	2
35	6	34	85.0	2
36	5	35	87.5	2
37	4	36 	90.0	2
38	3	37	92.5	2
39	2	38	95.0	2
40	1	39	97.5	2
41	0	40	100.0	2
Total				82 samples

Data sets	Firik and regular bulgurs used	Number of Data	Measured Color Parameters
		Total: 82	
DS1	FB1 + RB1	Calibration: 41	L*, a*, b*, C*, h
		Validation: 41	
		Total: 82	
DS2	FB2 + RB3	Calibration: 41	L*, a*, b*, C*, h
		Validation: 41	

Table 5. Characteristics of the two experimental data sets utilized in the study



Figure 3 Six samples of firik bulgur and regular bulgur mixture from first data set (DS1) (above) and second data set (DS2) (below) (Regular bulgur ratios in the mixture from left to right: 0%, 20%, 40%, 60%, 80%, 100%)

3. RESULTS AND DISCUSSION

Correlation analysis was performed between the color data (L*, a*, b*, C*, and h) and the regular bulgur ratio (%) in the mixture (adulteration level) for both data sets in the study. Then, PLS regression analysis was performed to estimate the regular bulgur ratio (%) in the mixture from the color parameter values. The findings are presented below.

3.1. Correlation analysis results

Correlation coefficients between the ratios of regular bulgur in the mixture (0-100%; 2.5% increment) and color parameters (L*, a*, b*, C*, and h) were calculated for both data sets (DS1 and DS2) and presented in Table 6. In addition,

the correlation relationships between the (adulteration regular bulgur ratio (0-100%) in the mixture and the color parameters (L*, a*, b*, C*, and h) are illustrated in Figure 4 for both data sets (DS1 and DS2). For the first data set (DS1), medium-to-high (r=0.72) correlation values were observed between the regular bulgur proportions in the mixture and color parameters b* and C* while medium level correlation (r=0.52) for L* parameter and low level correlation (r=0.20 and 0.12) for the a* and h parameters were observed (Table 6). As of the second data set (DS2), very high correlations (r=0.90-0.92) were found between the regular bulgur proportions in the mixtures and the four color parameters (a*, b*, C*, and h) while the correlation was lower (r=0.75) for the remaining color parameter L*

(Table 6). A better overall correlation was observed for the second data set (DS2) compared to the first data set (DS1) based on the results of the correlation analysis. This could be due to the higher similarity between the regular bulgur and firik bulgur in the DS2 data set compared to the DS1 data set.

3.2. PLS Regression analysis results

Half (n=41) of the total number of bulgur mixture samples (n=82) in each of the data sets (DS1 and DS2) were used as the model development purpose (calibration) and the remaining half (n=41) were used as the validation data set.

Statistical data regarding the estimation performance of the models for the prediction of regular bulgur ratio or the adulteration level (%) in the mixture from the color data (L*, a*, b*, C*, and h) are enlisted in Table 7. Based on the results, it was determined that the regular bulgur ratio (%) in the mixture could be estimated with lower accuracy (RMSEP=19%; R²=0.57) in the

first data set (DS1) and with higher accuracy in the second data set (DS2) (RMSEP=12%; R²=0.83). Regarding the two different color models employed in the study (L*a*b* and L*C*h), no significant difference was observed between these two color models in terms of prediction performance of the regression models (Table 7). In addition, the score plot of the regression model obtained with the L*a*b* color data for the DS2 data set is illustrated in Figure 5. In the score graph, it is seen that the samples with lower proportions (approximately 0-50%) of regular bulgur in the mixture samples are clustered on the left side of the graph while the samples with higher proportions (approximately 50-100%) are clustered on the right side of the graph. Furthermore, the estimated vs. measured values graph is presented in Figure 6 by using the L*a*b* color model for the DS2 data set. It can be seen in this graph that the samples in the validation set are dispersed close to the 1:1 line (Figure 6).

Table 6. Correlation coefficients between the ratio of regular bulgur (%) in the mixture and five color parameters (L^* , a^* , b^* , C^* , and h)

Data sets	L*	a*	b *	C*	h
DSI	0.52	0.20	0.72	0.72	-0.12
DS2	0.75	0.92	0.90	0.90	-0.91

Table 7. Statistical data on the regression models for the estimation of the regular bulgur ratios (%) in the mixture for the data of the two color models ($L^*a^*b^*$ and L^*C^*h)

Data	Color	Explained	Explained				
sets	models	variations in X *	variations in Y*	R ² cal	R^2_{val}	RMSEC	RMSEP
DOI	L*a*b*	PC1: 60% PC2: 28%	PC1: 56% PC2: 6%	0.62	0.57	18.7%	19.0%
DS1	L*C*h	PC1: 64% PC2: 25%	PC1: 54% PC2: 8%	0.62	0.57	18.7%	18.9%
DS2	L*a*b*	PC1: 93% PC2: 5%	PC1: 86% PC2: 2%	0.88	0.84	10.5%	11.6%
D52	L*C*h	PC1: 92% PC2: 4%	PC1: 85% PC2: 2%	0.87	0.83	10.8%	11.8%

^{*}X: Color data variables, Y: Regular bulgur proportions in the mixture samples, PC1: First principal component, PC2: Second principal component, RMSEC: Root mean square error of calibration, RMSEP: Root mean square error of prediction, R²cal: Coefficient of determination for calibration, R²val: Coefficient of determination for validation

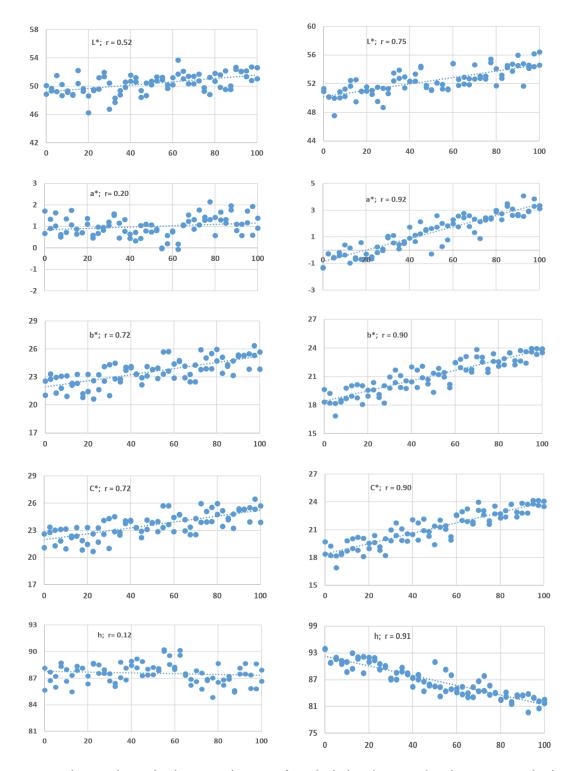


Figure 4 Correlation relationship between the ratio of regular bulgur (%0-100) in the mixture and color parameters (L*, a*, b*, C*, h) of the 82 samples for the two data sets (DS1: left; DS2: right) (X axis: the proportion of regular bulgur (%) in the mixture, Y axis: color data)

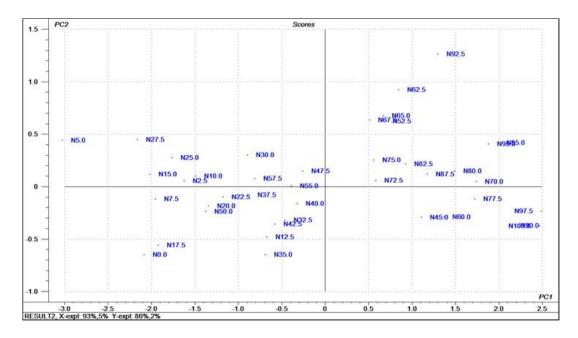


Figure 5 Score plot from the PLS regression with $L^*a^*b^*$ color parameters for the second data set DS2 (The letter "N" and the numerical values in the data labels indicate the proportion of regular bulgur in the mixture samples)

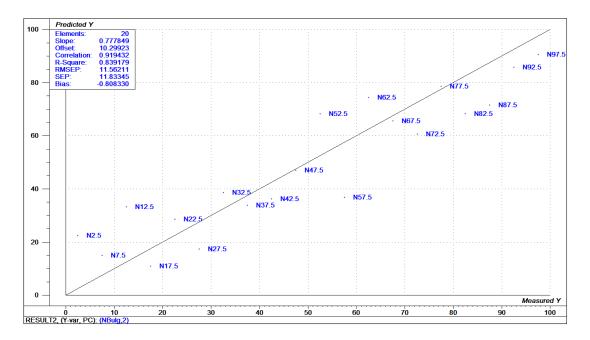


Figure 6 Predicted vs. measured graphs for the proportions of regular bulgur in the mixture samples from the PLS regression by using $L^*a^*b^*$ color data for the second data set DS2 (The letter "N" and the numerical values in the data labels indicate the proportion of regular bulgur in the mixture)

Food adulteration is a serious problem risking consumer health and causing economic losses (Aslam et al., 2023; Momtaz et al., 2023). Many food chemical additivies have a potential to cause health problems and diseases including cancer (Sannino and Savini, 2021; Bautista, 2023). Traditional chemical analysis techniques are being used for the determination of fraud and authentication in foods; however, these methods possess some disadvantages such as taking long time, requiring sample preparation requiring and pre-treatment, chemical substances, labor, and costs. For this reason, research studies are carried out to determine food adulteration in a short time with less labor and expense by non-destructive and fast measurement instruments including chromameters, multispectral and hyperspectral digital cameras, machine vision, near infrared reflectance spectroscopy (NIRS), spectroscopy, nuclear magnetic resonance (NMR), e-nose, e-tongue, terahertz imaging, and laser induced breakdown spectroscopy (LIBS), etc. (Aslam et al., 2023). Kiani et al. (2017)investigated the camera image processing system for the detection of safflower and artificially colored yellow saffron (10-50%) added to saffron for adulteration. Sezer et al. (2018) examined the detection level of chickpea, corn and wheat additives mixed to Arabica coffee by laser-induced fragmentation spectroscopy. Similarly, Sezer et al. (2019) examined the detection of green peas and spinach products in pistachios with the same instrument. Keskin et al. (2021) studied the feasibility of a chromameter to discriminate pure and mixed organic and conventional red pepper powders. In another work, Keskin et al. (2022) used NIRS technique to estimate applied microwave power of dried and powdered black carrots.

The use of advanced data analyses methods including machine learning and deep learning techniques has a significant potential to increase

the performance of the detection of food adulteration (Sneha et al., 2023).

In food industry, the color data measured by a color meter have been utilized to evaluate various quality parameters of the food products. Various investigations have been carried out on the evaluation of the various quality parameters of the food stuff including: ripeness of vegetables and fruits, the color of the raw and processed foods including flours, doughs, breads, molasses, oils, juices, meats, chocolates, dairy products, jams, milks, and pastas, etc. (Keskin et al., 2017).

Firik bulgur is more nutritious than regular bulgur but it is three to four times more expensive than regular bulgur. Adulteration is common by mixing regular bulgur to firik bulgur. It is very difficult if not possible for the human eye to detect the adulteration level in firik bulgur. There have been significant numbers of research studies for the detection of fraud in food products but no study has been conducted on the adulteration of firik bulgur. This study examined the possibility of using chromameter to detect the proportion of regular bulgur in firik bulgur offering a fast, nondestructive and low-cost detection of fraud. The results showed that the regular bulgur ratio in the mixture could be estimated from either of the two color models (L*a*b* and L*C*h) with reasonable accuracy. The prediction performance was slightly better with the second data set (DS2) (RMSEP=12%; R²=0.83) compared to the first data set (DS1) (RMSEP=19%; R²=0.57).

The result of this preliminary study is promising for the use of a hand-held colorimeter to differentiate the adulterated firik bulgur mixed with regular bulgur with reasonable accuracy. The chromameter used in this study had three spectral channels (red, green, and blue) obtaining reflectance data from the measured sample. More precise systems that have higher

number of channels such as hyperspectral digital cameras and near infrared and mid infrared spectroscopy can be used to obtain better results in future studies.

4. CONCLUSION

This study was carried out to examine the possibility of fast, non-destructive and low-cost detection of adulteration in firik bulgur by employing a hand-held chromameter. Two different data sets (n=82) with two different brands of firik bulgur were used in the study by creating a mixture of firik bulgur and regular bulgur with proportions from 0 to 100% with 2.5% increments.

It was determined that the regular bulgur ratio in the mixture could be estimated from the color data. The prediction performance was slightly lower with the first data set (DS1) (RMSEP=19%; R²=0.57) compared to the second data set (DS2) (RMSEP=12%; R²=0.83). There was no significant difference in the prediction accuracy of the prediction models using the two color models (L*a*b* and L*C*h); thus, either of these color models can be employed in the prediction. In sum, the results show that a hand-held colorimeter can be used to differentiate the adulterated firik bulgur obtained by mixing regular bulgur to firik bulgur with reasonable accuracy (R²=0.83).

In future studies, more advanced optical instruments with higher spectral bands including digital multispectral or higherspectral cameras and near infrared and mid infrared spectroscopy instruments can be investigated.

Ethical Approval

None.

Declaration of Interests

The authors of this study declared no potential conflict of interests.

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Author Contribution

Concept: MK Design: MK

Data collecting: MK Statistical analysis: MK Literature review: MK

Writing: MK

Critical review: MK

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