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Colour Change Analysis of Fig Fruit during Microwave Drying

Abstract

Investigation of qualitative indices for the pulsed microwave dried figs (*Ficus carica* L.) is accomplished through image processing techniques. Three hundred colour pictures of fig fruit before and after drying were prepared in RGB colour space. After converting the RGB colour space into $L^*a^*b^*$ units, colour values in $L^*a^*b^*$ units were analysed before and after drying at five levels of microwave power intensity and six pulsing ratio levels. Kinetic parameters for the colour change were determined using the total colour change parameter, chroma, hue angle and browning index. The results showed that the L^* value decreases with the pulsing ratio and increases with microwave power intensity while a^* values remains constant with the microwave power intensity. Values of hue angle for dried fig varied between 1.21 and 1.32 radian, i.e. the dried fruits presented an appealing yellow/orange colour. Additionally, increasing microwave power intensity led to higher browning indices. Based on the resulting values, an optimized microwave drying of fig will be achieved serving as a tool for enhanced economical processing of the fruit.

Keywords: fig, $L^*a^*b^*$, image processing, pulsed microwave drying

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Introduction

During microwave (MW) drying, quality preservation of the product is of utmost importance [1]. The term product quality includes three principal areas: nutritional value, acceptability and safety. Acceptability includes a large array of attributes such as visual appearance, flavour, aroma and texture [2]. The first quality judgement made by a consumer on a food at the purchase situation is its visual appearance. Colour is one of the most important appearance characteristics of food materials, since it influences consumer acceptability. Abnormal colours of food materials cause the product to be rejected by the consumer. Hence, many food producers utilize the psychological effect of colour to increase their products sale. On the other hand, the drying operation must be optimized to obtain high-quality products. With regard to quality, colour is a key property governing the initial acceptability of any food material [3].

Several research reports have investigated colour deterioration during drying for a large number of products. Colour change of dried products has been measured usually in units $L^*a^*b^*$ using a colorimeter or specific data acquisition. In recent years, image processing systems have been developed to objectively measure the colour of different products since they provide some obvious advantages over a conventional colorimeter, namely, the possibility of analysing each pixel of the entire surface of the product and determining the surface characteristics of products [4]. 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) [2]. 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 [5]. Unlike the RGB model, the $L^*a^*b^*$ model is device independent, providing consistent colour regardless of the input or output device such as digital camera, scanner, monitor and printer [6].

Although several researches have been carried out to measure colour characteristics of products during drying using colorimeter such as kiwifruit [3], garlic cloves [7], mint leaves [8], nettle leaves [9] and spinach [10], few researchers have concentrated on evaluating colour features based on image processing. Also, colour characteristics of fig fruit during MW drying have not been studied.

Since the qualitative parameters of fig are highly prone to thermal treatments, the present research was designed to minimize the deteriorating effects of drying process and hence to maintain the quality of fruit at the marketing terminals. The main objective of this research was to introduce a convenient method for measuring and evaluating the kinetics of colour changes of fig fruit during MW drying using image processing.

Materials and methods

Sample preparation

Figs (Rashe variety) were obtained locally from Sardasht, Iran, and stored in a refrigerator at 4 ± 1°C before they were used for the experiments. Just before drying, samples were taken out from the refrigerator to obtain ambient temperature (20 ± 2°C). They were visually inspected and damaged samples were eliminated before tests. Samples were then immediately weighed and placed in a 32 cm diameter tray and submitted to MW oven. No pretreatment was applied to the fresh products.

Drying was performed in a laboratory MW Oven (Panasonic 686S model, Matsushita Electric Ind. Co. Ltd., Japan; Figure 1). The tray and fan were modified so as to be controlled separately. The fan of the dryer worked continuously at 0.5 m/s air velocity throughout the experiments for moisture removal the sample tray was installed upon a motor driver located on top of a load cell (ZEMIC model, L6D – C3–5 kg) with an accuracy of 0.2 g under the dryer housing. A motor driver rotates the sample tray to evenly distribute the MW power and simultaneously the sample mass was recorded and displayed via a digital display integrated with the load cell. During MW drying, weight of the samples was measured at regular intervals (10 s). Subsequently, measured data were transferred to the PC for recording with a "National Instruments LabView" program (Run-Time Engine 6.0 version). Additionally, the control circuits of the oven were modified to allow the power-on and power-off durations to be controlled with a microcontroller, which could continuously and automatically adjust the on-off MW power.

Image acquisition system

An image capturing system was designed to provide an enclosed and uniform light illumination and to obtain standard images from the samples (Figure 2). The sizes of the capturing chamber were 30 cm (length), 20 cm (width) and 30 cm (height). A camera holder was inserted at the upside of the box and a colour CCD camera (DSC W 200 Sony, Japan) was placed at the centre of the holder upside down at a distance of 25 cm from the samples. The internal walls of the chamber were covered by a dark cardboard to eliminate light reflectance. Samples were illuminated using two parallel lamps (with one halogen tube in each lamp, Lighting Co., Iran). The angle between the camera lens and the light source axis was 90°. Totally, 300 images of fig fruit were acquired (150 images before drying and 150 images after drying).

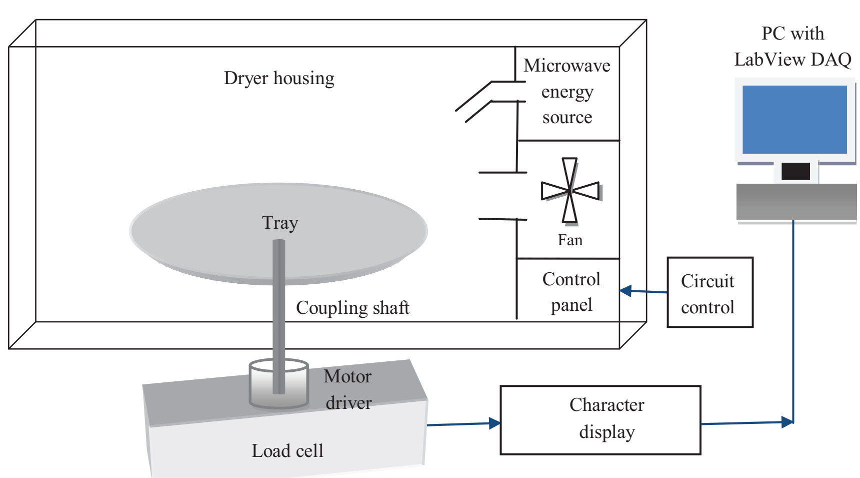

Figure 1 Schematic diagram of the MW drying system used in drying of fig fruit. Samples are placed over the tray.

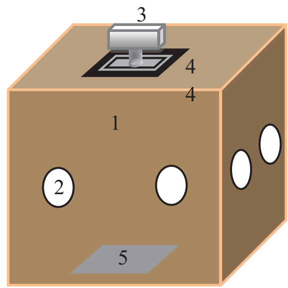

Figure 2 Image acquisition system; 1. Capturing chamber, 2. Fluorescent lamps, 3. CCD camera and lens, 4. Camera holder, and 5. Sample place.

Image preprocessing

Image preprocessing is the first step in image analysis. The quality of the final result of analysis is highly dependent on the image preprocessing stage [11]. Before processing of fig images, it was necessary that preprocessing be carried out to modify the non-uniform distribution of background light intensity and to remove any external material such as dust or sap, from the image background. Image preprocessing was performed in six steps as follows:

1. Obtaining grey images from the RGB space channels.
2. Obtaining binary image of samples using defined threshold values for R and G channels (R-G). In binary images, figs and background have value equal to 1 and 0 respectively.
3. Filling the holes in the binary image to obtain an actual binary image.
4. Removing the noise (small external materials with an area under 20 pixels) using opening operation.
5. Multiplying the obtained binary images in R, G and B channels.
6. Acquiring RGB images by combination of grey images obtained from the previous step.

Results of the above steps are shown in Figure 3.

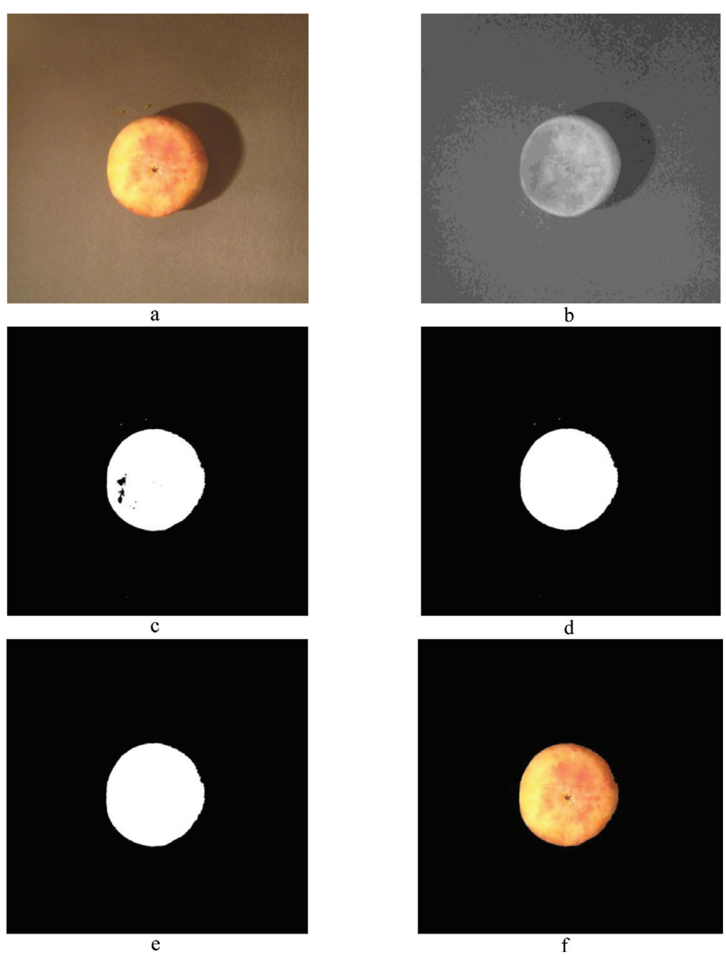

Figure 3 a. Original captured image, b. Grey images, c. Binary image, d. Actual binary image after filling operation, e. Noiseless image, f. Finally image after preprocessing.

Conversion of RGB images into $L^*a^*b^*$ units

In this study, the colour images were prepared in RGB colour space and then converted to $L^*a^*b^*$ units. The component of $L^*a^*b^*$ colour space was calculated using relations 1–4 [11]:

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

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

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

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:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 0.607 & 0.174 & 0.200 \\ 0.299 & 0.587 & 0.114 \\ 0.000 & 0.066 & 1.116 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \quad [4]$$

Kinetics of colour changes during drying

Drying was performed in a MW dryer with a digital accurate power control. The kinetics of colour changes of fig fruit before and after drying at five levels of MW power intensity (0.5, 1, 1.5, 2 and 2.5 W/g), and six levels of pulsing ratio (1.5, 2, 2.5, 3, 3.5 and 4) were investigated. These levels were selected according to data extracted from pretests, i.e. factors to guarantee a safe and suitable temperature of drying of fig fruit. The pulsing ratio, PR, was defined as follows and presented in Table 1.

Table 1 Defined pulsing ratios as a variable studied factor in the experiments.

Power on time (s)	30			60		
Power off time (s)	15	45	75	60	120	180
Pulsing ratio	1.5	2.5	3.5	2	3	4

$$\text{PR} = \frac{\text{Cycle power on time} + \text{Cycle power off time}}{\text{Cycle power on time}} \quad [5]$$

The colour values were expressed as L^*, a^* and b^* before and after drying. In addition, total colour change, chroma, hue angle and browning index (BI) were calculated from the values of L^*, a^* and b^* and used to describe the colour change during drying. The chroma or saturation index indicates colour saturation and is proportional to its intensity. The hue angle is another parameter frequently used to characterize colour in food products. An angle of 0 or 2π radian represents red hue, while angles of π/2, π and 3π/2 radian represent yellow, green and blue hues respectively [12]. The BI represents purity of brown colour. The total colour change (ΔE), chroma, hue angle and BI were calculated from the following equations [3, 13]:

$$\Delta E = \sqrt{(L_o^* - L^*)^2 + (a_o^* - a^*)^2 + (b_o^* - b^*)^2} \quad [6]$$

$$\text{Chroma} = \sqrt{(a^{*2} + b^{*2})} \quad [7]$$

$$\text{Hue angle} = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad [8]$$

$$BI = \frac{[100\,(x - 0.31)]}{0.17}, \quad x = \frac{(a^* + 1.75L^*)}{(5.645L^* + a^* - 3.012b^*)} \quad [9]$$

where L^*, a^* and b^* values correspond to colour values of figs at the end of drying and the values of L_o^*, a_o^* and b_o^* refer to fresh fig fruits. All experiments were performed in five replicates and then averaged.

Results and discussion

The results of colour parameters of fig fruit after MW drying are presented in Figure 4 for L^*, a^* and b^* values respectively. The L^* value decreases with the pulsing ratio and increases with MW power intensity since dried figs tend to get darker with increase in pulsing ratio and decrease in MW power intensity. This may be due to the increasing drying time as a result of increasing pulsing ratio and decreasing MW power intensity. Alibas [9] reported that larger MW power causes an increase in lightness of dried nettle leaves which corresponds with our results. In the case of chromatic parameter a^*, it was found that the MW power intensity did not significantly affect the alteration of a^*. However, the reduction of redness (a^*) was observed at lower pulsing ratios. In general, a^* parameter increase is not desired since it represents severe redness of the product, which is not at all acceptable for processed figs; therefore, decreasing pulsing ratio and increasing MW power intensity cause enhance the cosmetic appearance of the products. In MW drying, heat is generated through the dipole changing mechanism of MW radiation [14] and MW energy selectively

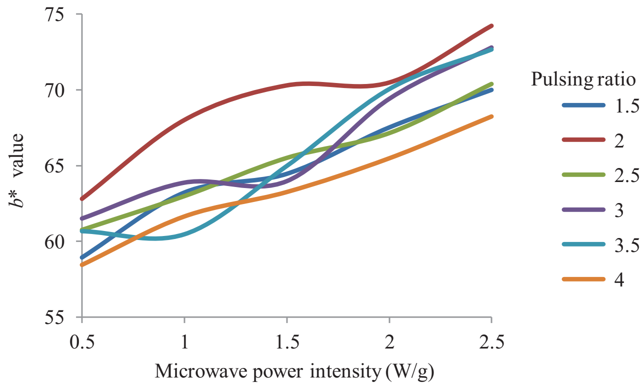

Figure 4 Changes in the colour parameters of fig fruit as a function of MW power intensity at selected pulsing ratio after MW drying.

warms up the areas with high liquid content [15]. Therefore, the surface temperature of the fruit will not increase sharply during MW drying. Hence, a^* value increase has not been seen with increasing MW power intensity. The b^* colour parameter measures the yellowness of the product. b^* values tend to increase with an increase in MW power intensity. This result is consistent with those of Alibas [9] for nettle leaves. On the other hand, the b^* values decreased in higher pulsing ratios due to the increase in drying time which promotes browning reactions.

Chroma is the indicator of colour saturation and intensity. The higher its values, the more desirable they are. Chroma was calculated using eq. [7] and presented in Figure 6. The chroma value enhanced with the increase in MW power intensity and decrease in pulsing ratio due the reduction of drying time. This result is in consistent with those of Alibas [9] for nettle leaves. Values of chroma for dried fig varied between 62.04 and 76.86. A typical illustration of this is shown in Figure 5. As depicted, at high power intensity, i.e. 2.5 W/g, chroma was elevated leading to a better appearance of the product.

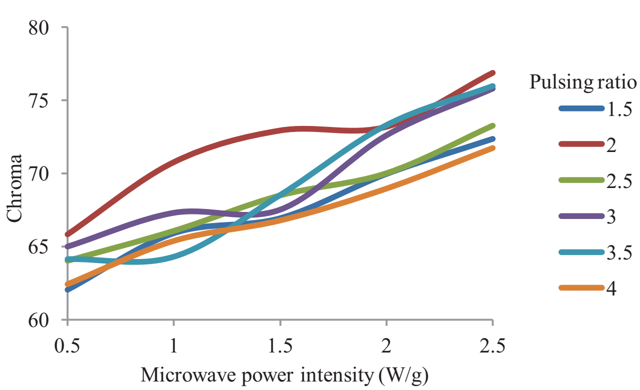

Figure 5 Variation of chroma as a function of MW power intensity at selected pulsing ratio after MW drying.

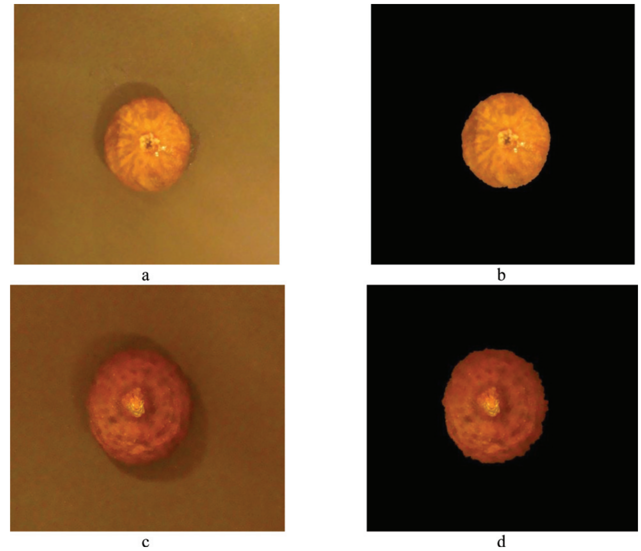

Figure 6 Typical images of dried fig under different conditions; a) original captured image and b) final preprocessed image after drying at 2.5 W/g MW power intensity; c) original captured image and d) final preprocessed image after drying at 0.5 W/g MW power intensity.

As observed in Figure 7, the hue angle values increased slowly with MW power intensity. Also, in small values of pulsing ratio, dried samples had larger values of hue angle. The values ranged from 1.21 radian at 0.5 W/g MW power intensity to 1.32 radian at 2.5 W/g MW power intensity, when pulsing ratios were 4 and 1.5 respectively.

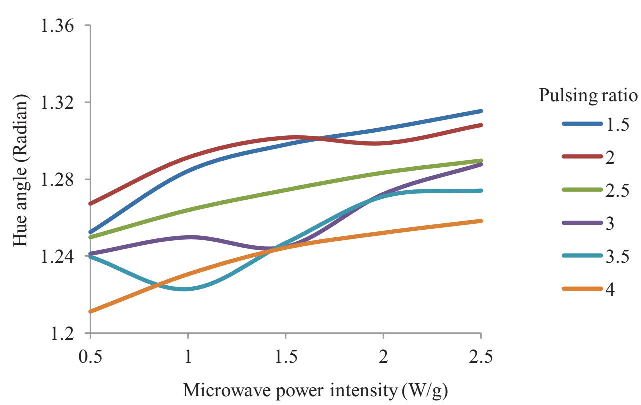

Figure 7 Variation of hue angle as a function of MW power intensity at selected pulsing ratio after MW drying.

The variation in the BI value of fig fruit after drying is presented in Figure 8. Increasing MW power intensity causes an increase in BI. Since non-enzymatic browning is temperature dependent and increasing MW power intensity can increase the internal temperature of

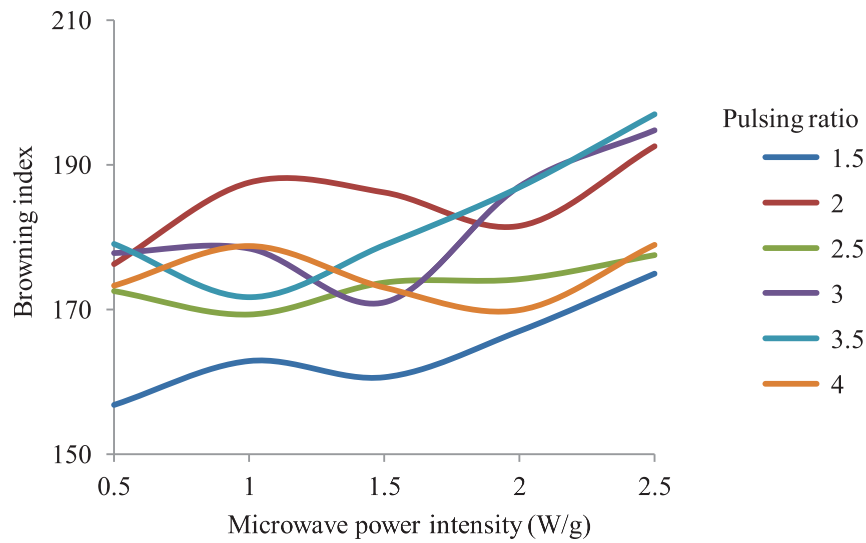

Figure 8 Variation of BI of dried figs as a function of MW power intensity at selected pulsing ratio after MW drying.

samples, it is reasonable to expect that the samples dried in larger MW power intensity showed greater BI than samples dried in smaller MW power intensity. The highest BI (196.94) was obtained at 2.5 W/g MW power intensity, when the pulsing ratio was 3.5. However, the BI of dried fig should not be interpreted as a result of browning reactions during drying but its inherited characteristics. The desired BI values for dried fig should be closer to the BI value of fresh fig. The lowest value of this index, equal to 156.82, was calculated at 0.5 W/g MW power intensity, when the pulsing ratio was 1.5. Considering the decrease in drying time and consequently the decrease in browning reactions with decreasing pulsing ratio, it could be concluded that BI declined with decreasing the pulsing ratio.

The mean values of colour parameters of fresh samples (150 images) captured before drying are presented in Table 2. An important loss was noted in the values for L^* and a^* of dried fig when compared with fresh fruits (Table 2), which agrees with the results of the study on carrot [16] and another study on spinach [10].

Table 2 Values of derived colour measures of fresh fig.

Colour parameter	L^*	a^*	b^*	Chroma	Hue angle	Browning index
Mean values	83.37	24.74	61.72	66.90	1.18	143.22
Standard deviation	1.81	1.52	1.96	1.59	0.03	8.93

Table 3 Total colour change of fig fruit under various MW power intensities and pulsing ratios.

Pulsing ratio MW power intensity (W/g)	1.5	2	2.5	3	3.5	4
0.5	8.55	8.21	8.38	8.51	9.23	9.23
1	8.25	8.52	8.47	9.26	7.57	8.24
1.5	8.45	7.34	9.11	8.17	8.87	9.37
2	10.39	10.34	8.19	9.56	9.34	10.21
2.5	10.87	10.21	10.31	10.92	9.51	8.99

Table 3 illustrates the total colour changes in fig fruit (ΔE) under various drying conditions, taking into account changes in lightness, redness and yellowness. The total colour change in samples increased with MW power intensity due to rise of browning reactions. Keskin et al. [17] in baking of cookies reported similar results. Nevertheless, it has to be noted that the initial colour and moisture content of samples were not the same in different drying conditions. Therefore, changes in colour values are not only due to browning reactions but could also depend on the initial colour of products.

Conclusion

The effects of MW power intensity and pulsing ratio on the colour change of fig fruit during drying were investigated in this study. Increasing MW power intensity can provide a desirable contribution to light yellowish colour of dried fig (increased L^* and b^* values). Nevertheless, from the growing total colour changes, we conclude that 2.5 W/g is the optimum MW power intensity level in the MW drying of fig with respect to colour criteria. Image processing is an easy, precise, representative, objective and inexpensive technique to measure and analyse colour evolution in the food industry because a large amount of information can be obtained from measurements at the pixel level, which allows a better characterization of products. Thus monitoring colour changes of fig fruit during drying by image processing could be suitable for optimizing MW drying process and quality preservation of dried fig.

Nomenclature

a^*	Colour redness (+)/greenness (–) coordinate, dimensionless
b^*	Colour yellowness (+)/blueness (–) coordinate, dimensionless
BI	Browning index, dimensionless
L^*	Colour brightness coordinate, dimensionless
MW	Microwave
PR	Pulsing ratio
ΔE	Total colour change, dimensionless

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