Effect of gamma irradiation pretreatment on dried mushroom slices color and area shrinkage

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Abstract: Non-thermal processes such as irradiation are desierable methods to be used in combination with thermal ones in order to improve the quality of agricultural products. In this study, mushroom slices were initially irradiated under various doses (0 as control, 1.2, 2.4 and 3.6 kGy) and then dried at different temperatures (50 ℃, 60 ℃, 70 ℃). Then, the machine vision and image processing techniques were used to investigate any color changes and area shrinkage of dried mushroom slices. By increasing the irradiation dose, the change of the color indices ($L*$ and $b*$), total color difference (ΔE), browning index and chroma decreased. While high temperatures had negative effect on these parameters except chroma. Moreover, the variation range of $a*$ was insignificant during drying and the hue angle was between 70° to 78°. The zero and first order models for $L*$, $b*$ and ΔE, as a function of drying time, showed high correlation coefficient for all treatments (0.91–0.99). Regarding shrinkage, by increasing irradiation dose and drying temperature, the area shrinkage slightly increased, where the temperature was more effective than irradiation dose.

Keywords: irradiation, drying, mushroom, machine vision, color, image processing

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1 Introduction

In general, most of the fresh agricultural products, including edible mushrooms, could be easily spoiled due to the sensitivity of their texture, the presence of perishable nutrients, high moisture content and some other parameters. Therefore, their quality deteriorates immediately after harvesting, which is the major issue for their distribution and marketing (Akram and Kwon, 2010). Drying is one of the important methods of preservation for the products with high moisture, especially the mushroom. This method reduces deterioration of product due to chemical reactions, also reduces costs of transport, packaging and storage due to the weight and volume reduction (Dadali et al., 2007; Doymaz, 2014). However, the drying could potentially cause some visual and color changes mainly under long drying time and high temperatures, which could severely damage the pigments due to enzymatic or non-enzymatic browning (Muliterno et al., 2017). Color, due to its close association with other factors such as freshness, ripeness, favorable conditions and safety features, is an important parameter for the quality of agricultural products and foodstuffs (Demiray and Tulek, 2015). There are several approaches to preserve the quality of product and reduce the

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browning of mushrooms during drying process. All of which focus on the suitability of the dryer and the application of pretreatments prior to drying (Dinani et al., 2015). The blanching, as a pretreatment, usually causes the softening of the texture after drying (Ahrné et al., 2003). Therefore, it is necessary to use suitable pretreatments in order to increase drying rate as well as preserving the quality. In this regard, the effects of gamma irradiation on shelf life (Jouki and Khazaei, 2014; Lescano, 1994), physicochemical (Jiang et al., 2010; Najafabadi et al., 2017), chemical (Fernandes et al., 2017; Mahto and Das, 2014), physical (Fernandes et al., 2012), and qualitative properties of agricultural products (Adam et al., 2014; Wani et al., 2008) have been already investigated. Also in the recent years, its application to improve the safety in dried foods has been examined (Cetinkaya et al., 2006). However, the usage of irradiation prior to drying, in order to improve the color and texture, has been limited. For instance, improving the dehydration efficiency of vegetables, grapes and plums (Wierbicki, 1986), oyster mushroom (Kortei et al., 2016), drying characteristics of rice (Yu and Wang, 2007) and wheat (Yu and Wang, 2006) are some of the existing reports where the effect of the combination of irradiation and drying have been investigated.

Shrinkage, as an important quality parameter, could continuously occur during drying process and tremendously affect the texture, appearance and the overall quality of the dried product. Machine vision is a new method which measures the color and the area of product (Mohebbi et al., 2009) by which one could evaluate the rate of shrinkage in order to decrease or control during drying process (Ebrahimi et al., 2013). This technique had been used by: Chen and Martynenko (2013) for blueberries, Tian et al. (2016) for Shiitake mushrooms, Yan et al. (2008) for pineapple, mango and banana. Image processing obtained from the slices of apple during drying showed that the change of $L*$ value was insignificant. But the values of $a*$ and $b*$ increased and the area of slices decreased (Fernandez et al., 2005).

As it was described, so far with the best of our knowledge, the effects of gamma irradiation at various doses, as a pretreatment, in combination with hot air drying on the physical properties of button mushroom slices, as a highly perishable vegetable, have never been investigated. Therefore, in the present study, the effects of gamma irradiation pretreatment on color and area shrinkage during drying process of mushroom slices using image processing techniques have been examined.

2 Materials and methods

2.1 Irradiation and hot air drying of button mushrooms

The fresh button mushrooms (*Agaricus bisporus*) were purchased from Tehran’s vegetable market (4,281 ft, 51°30'E) and packed in polyethylene bags (thickness of 40 micrometers). The packages were irradiated (0, 1.2, 2.4 and 3.6 kGy, dose rate 1.98 Gy sec^{-1}) by ^{60}Co gamma rays irradiator (GC-220, Nordion, Canada) at ambient temperature (Atomic Energy Organization, Tehran, Iran) (4,281 ft, 51°30'E). Then, the irradiated samples were stored at 4℃ prior to hot air drying. The initial moisture content of mushrooms (92.5% w.b.) was measured using oven method (24 h at 105℃) (Özbek and Dadali, 2007).

For each experiment, 50 g of irradiated mushrooms were cut by meat slicer (thickness 3 mm) and dried, using a thin layer dryer equipped with machine vision systems (Figure 1), at 50℃, 60℃ and 70℃ with air speed of 1 m s^{-1}. Drying was ended when the moisture equilibrium was reached. Imaging was performed by a video camera equipped with a charge-coupled device（CCD） sensor (HPK-6301S, Hi-Peak, Taiwan). The first real-time image was read by MATLAB R2014a program. Then every five minutes an image was saved in a file and immediately image processing was performed to measure and analyze the parameters based on written code in the program. During drying, weight of the samples was recorded per minute by a digital balance (GF-6000, AND, Japan) with accuracy of 0.01 g.

2.2 Image processing

L^*, a^* and b^* color indices, due to the uniform distribution of color, was used to calculate the color of mushrooms slices during drying (Sampson, 2011). In this space, L^* represents black (0) to white (100), a^* green (-120) to red (+120) and b^* blue (-120) to yellow (+120) (Yam and Papadakis, 2004). Image processing was conducted by MATLAB R2014a in four stages including: the isolation of the image from background (Figure 2b), multiplication of binary image matrix at the original image (Figure 2c), the image color space conversion from RGB to $L^*a^*b^*$ (Figure 2d) and finally the conversion RGB values to L^*, a^*, b* values. It needs to be noted that L^*, a^*, and b^* values obtained from image processing was calibrated by Hunterlab (Coloorflex, USA) as a standard colorimeter (León et al., 2006). To calculate the area of the mushroom slices, after isolation of the image from background, pixels with value of 1 was counted and considered as the area value.

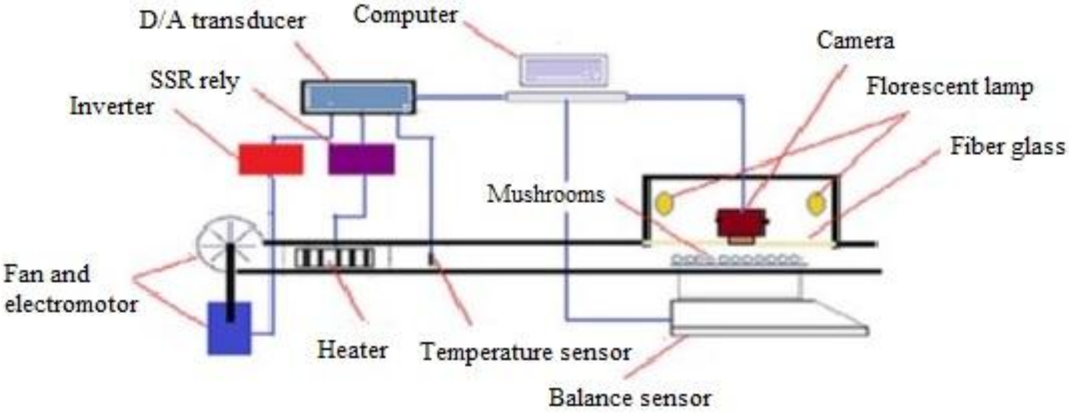
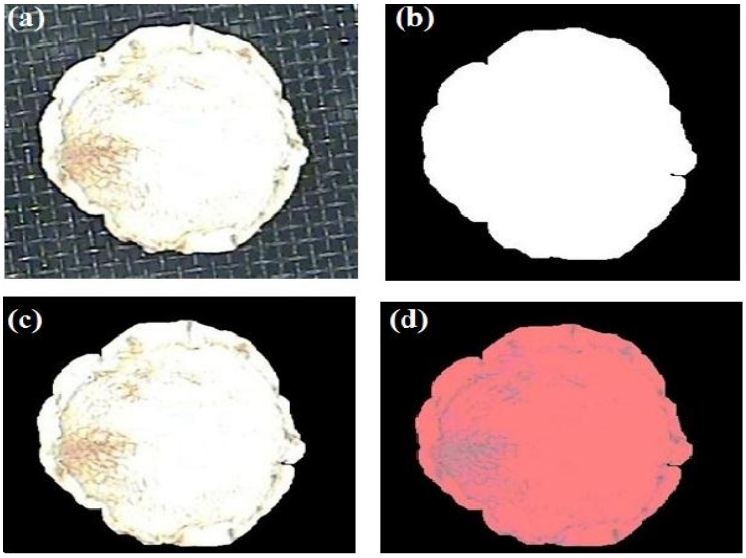


Figure 1 Schematic of the thin layer dryer based on machine vision systems



(a) Original image (b) Binary image (c) The original image with black background (d) and image converted to $L^*a^*b^*$

Figure 2 Image processing stages

2.3 Color analysis

The total color difference (ΔE), as an indicator of the color changes of the sample in comparison with the initial color value (L_0^*, a_0^*, b_0^*), was calculated as follows (Mohammadi et al., 2008):

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \qquad (1)$$

where L^*, a^* and b^* are degree of lightness, redness and yellowness, respectively; L_0^*, a_0^* and b_0^* indicate the reading of those parameters at initial time.

Browning index (BI), as the change of products color toward the browning, was calculated using the following equation and chroma, as the degree of pure color that diluted by white light, was calculated as follows (Aral and Beşe, 2016):

$$BI = \frac{100(x-0.31)}{0.17} \quad (2)$$

where, $x = \frac{a^*+1.75L^*}{5.645L^*+a^*-3.012b^*}$

$$\text{Chroma} = \sqrt{(a^{*2} + b^{*2})} \quad (3)$$

Hue is a color property, that describes a pure color which defines as an angle, was calculated using the following equation. Colors of red, yellow, green and blue dedicated to 0°, 90°, 180° and 270°, respectively (Karabulut et al., 2007).

$$Hue\ angel = tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (4)$$

2.4 Modeling of color changes

In this study, modeling for the values of color index and total color difference as a function of drying time was performed. Zero order (Equation 5) and first order (Equation 6) were used for modeling (Ebrahimi et al., 2013).

$$C = C_0 + kt \quad (5)$$

$$C = C_0\, exp(-kt) \quad (6)$$

where, C and C_0 are the amount of variable at time t and t=0, respectively; k is kinetics constant of zero and first order model.

2.5 Shrinkage analysis

After measuring the area of slices every five minutes, area shrinkage ($AS_{(t)}$) was calculated from Equation 7 (Aprajeeta et al., 2015), where A_t is the area at time t, and A_0 is the area at the beginning of process (t =0).

$$AS_{(t)} = \frac{A_t}{A_0} \quad (7)$$

2.6 Statistical analyses

The experimental data was analyzed based on completely randomized design with three replications. Its analysis of variance (ANOVA) was performed by SPSS 16.0 software.

3 Results and discussion

3.1 Calibration of color indices

The results obtained from measuring color by standard colorimeter and image processing showed reasonably high correlation coefficients for L^* (0.9003), a^* (0.9583) and b^* (0.930). Finally, the following linear relationships for converting data from color measurement by image processing to real values were found:

$$L^* = 1.609L_1^* - 26.633 \quad (8)$$

$$a^* = 1.928a_1^* + 6.606 \quad (9)$$

$$b^* = 1.655b_1^* - 3.550 \quad (10)$$

3.2 Color indices (*L*a*b**) and total color difference (ΔE)

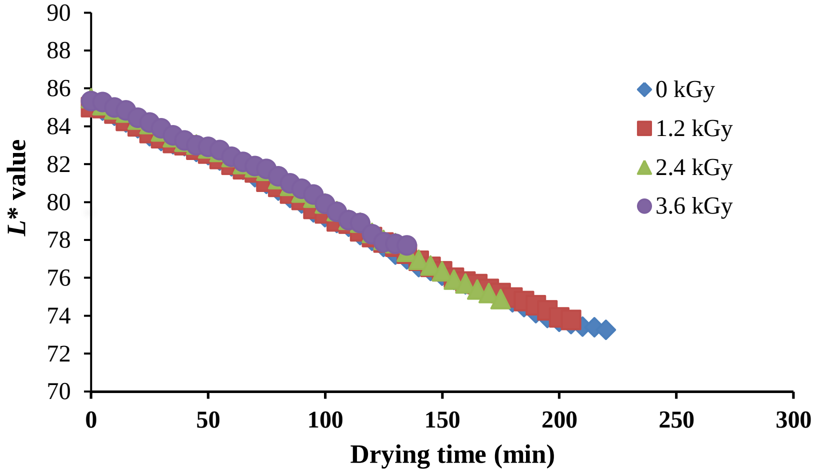
On the basis of our findings, the L^* of mushrooms decreased during drying process and where the reduction for non-irradiated samples was more pronounced than irradiated ones (Figure 3a). Therefore, irradiation as a non-destructive method was effective in preserving the lightness. By increasing the irradiation dose, the length of the drying time decreased. Also change in the L^* value of mushrooms during drying was linearly and the overlapping of the graphs showed that the rate of decrease was the same in all irradiation doses.

By increasing the drying temperature, the time required for drying decreased, but the rate of color change (lightness) increased (Figure 3b). This confirms that 50℃ was the most desirable drying temperature. In line with present study, Kortei et al. (2016) reported that the L^* for irradiated sliced oyster mushroom that had been in polypropylene packaging for 12 months was higher than non-irradiated at the same temperature. Also Wang and Chao (2003) reported that the irradiation doses up to 6 kGy and temperatures of drying up to 65℃, increased the value of L^* in potato slices, while at higher doses and temperatures this value decreased.

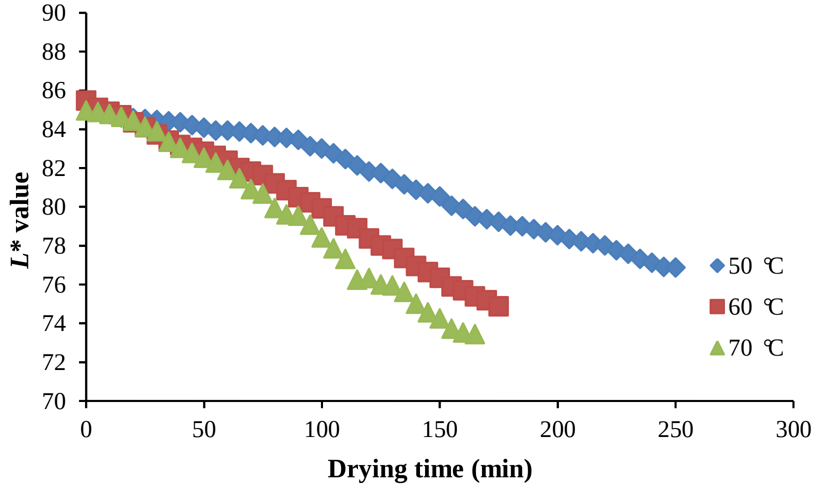
Despite L^*, the changes of a^* was not significant and therefore, cannot be used for color change evaluation. For a better understanding, average (Ave) and standard deviation (S.D) of a^* are listed in Table 1 at different treatments. The positive values of a^* under all treatments indicate the tendency to redness. Dinani and Havet (2015) reported that pretreatment of voltage (21 kV) before drying of mushrooms had a significant effect on lightness and a^* index.

Regarding b^*, it increased during drying process, but the rate of increase at 2.4 and 3.6 kGy were insignificant (Figure 4a) more likely due to its effect on the reduction of drying time. However, by increasing temperature, the b^* increased (Figure 4b). This results showing that the drying time reduction alone is not enough and the rate of color change is also very important. Demiray and Tulek (2015) reported that b^* values of carrot decreased during drying process and the amount of this reduction was greater at higher temperatures. In another study on oyster mushroom, by increasing drying temperature, the L^* decreased but b^* value increased (Kotwaliwale et al., 2007).

With regard to the total color difference (ΔE) it was found (Table 4) that by increasing temperature, its significantly increased ($p < 0.05$) and the minimum and maximum changes of color were belonged to the irradiated (3.6 kGy and dried at 50 ℃) and non-irradiated samples (dried at 70 ℃), respectively. It had been reported that gamma irradiation could inactivate some enzymes in which are effective in color changes (Maskan, 2001). Wang et al. (2015) also noticed that by decreasing the moisture content in shiitake mushrooms during drying, the L^* decreased but a^* and b^* values increased.

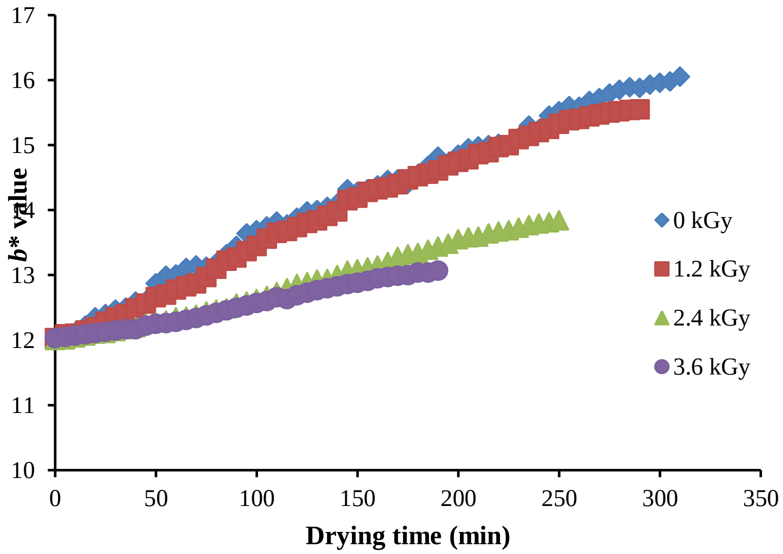


(a) irradiation doses (air temperature 60 ℃)

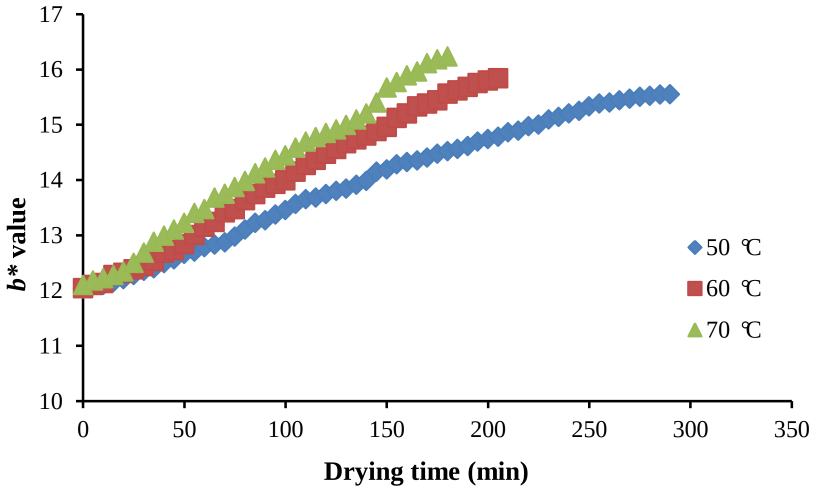


(b) drying temperatures (irradiation dose 2.4 kGy) on the lightness (L^*) of dried mushroom slices as a function of drying time

Figure 3 Comparison of the influence of different (a) and (b)



(a) irradiation doses (air temperature 50 ℃)



(b) drying temperatures (irradiation dose 1.2 kGy) on *b** of dried mushroom slices as a function of drying time

Figure 4 Comparison of the influence of different (a) and (b)

3.3 Color modeling

The results of modeling for the color indices (*L**, *b** and ΔE), as a function of drying time, are shown in Tables 2 and 3. Modeling of *a** was waived, because of its insignificant change. The correlation coefficient for all indices were above 90%, however zero order described better than first order due to its simplicity. According to Table 2, the absolute value of kinetic constant (*k*) for *L** index and total color difference (Δ*E*) was almost the same. The results also indicate that *L** had the most effect on ΔE. In addition, by increasing the temperature, k increased in both models indicating the high rate of color change at high temperatures (Mohammadi et al., 2008). It is also reported, the color change of agricultural products is a function of moisture content (Bonazzi and Dumoulin, 2011; Devahastin and Niamnuy, 2010). In most cases, by increasing the irradiation dose (in zero order model), the k for the *L** increased, for ΔE was not clear, but for *b** index decreased. The rate of *b** change was insignificant at high irradiation doses. In case of first order model, by increase in irradiation dose, k for *L** was almost constant whereas for *b** decreased. On the basis of existing reports, that first order model was suggested appropriate for *L** and *b** in pineapple (Chutintrasri and Noomhorm, 2007) but zero order one for ΔE in oyster mushroom (Engin, 2019).

Table 1 The change of a* index regarding to the drying time (t)

Dose kGy)	**50 ℃**			**60 ℃**			**70 ℃**		
	*a**		t (min)	*a**		t (min)	*a**		t (min)
	Ave	S.D		Ave	S.D		Ave	S.D	
0	2.69	0.73	310	2.92	0.83	220	3.34	1.00	180
1.2	2.74	0.69	290	2.78	0.82	205	3.24	1.07	180
2.4	2.74	0.70	250	2.82	0.81	175	3.30	1.04	165
3.6	2.37	0.70	190	2.99	0.89	135	3.18	1.07	130

Table 2 The results of modeling for the color indices (*L, *b** and ΔE) in zero order model**

		T=50 ℃			**T=60 ℃**			**T=70 ℃**		
Dose (kGy)	C	K	C_0	R^2	k	C_0	R^2	k	C_0	R^2
0	$L*$	-0.030	85.33	0.99	-0.057	85.04	0.99	-0.075	85.38	0.99
	$b*$	0.013	12.19	0.99	0.021	12.06	0.99	0.030	12.09	0.99
	ΔE	0.034	-0.13	0.99	0.062	-0.05	0.99	0.083	-0.36	0.99
1.2	$L*$	-0.033	85.65	0.98	-0.057	85.2	0.99	-0.075	85.66	0.99
	$b*$	0.013	12.07	0.99	0.019	1.96	0.99	0.023	12.03	0.99
	ΔE	0.036	-0.26	0.99	0.061	-0.21	0.99	0.081	-0.67	0.99
2.4	$L*$	-0.035	85.85	0.97	-0.061	85.78	0.99	-0.077	85.99	0.98
	$b*$	0.007	11.89	0.99	0.012	11.97	0.99	0.015	11.94	0.99
	ΔE	0.037	-0.45	0.98	0.064	-0.30	0.99	0.081	-0.92	0.99
3.6	$L*$	-0.037	86.01	0.94	-0.059	85.74	0.99	-0.080	85.98	0.98
	$b*$	0.005	11.97	0.99	0.008	12.03	0.99	0.011	12.03	0.99
	ΔE	0.039	-0.27	0.95	0.063	-0.34	0.99	0.085	-1.01	0.98

3.4 Browning index, chroma and hue angle

Browning index of the all dried mushrooms is shown in Table 4. The value of this index increased significantly at the end of drying process ($p < 0.05$) which its initial value ranges was from 16.07 to 16.64 in beginning of this process. The effect of irradiation pretreatment in reducing the browning was more than control of dryer temperature. There was a linear relation between temperature and the browning index. According to Equation 2, $L*$ had the greatest effect on the browning index. It was also reported that different pretreatments such as washing with water, immersion in potassium metabisulfite, sucrose and sodium chloride before drying can improve the color preservation (Walde et al., 2006). Nontheless, in all cases a series of chemical reactions were occurred upon heating which was not safe. But in the present study, irradiation reduced drying time, likely decreased the formation of non-enzymatic reactions by inactivated some of the natural enzymes such as polyphenol oxidase, phenylalanine ammonia lyase and peroxidase prior to the drying process. These enzymes are mostly responseble for the formation of brown pigments (Beaulieu et al., 1999; Benoît et al., 2000).

With reference to chroma, it increased due to the increase of $a*$ and $b*$ values. The statistical analysis showed significant differences among treatments ($p < 0.05$; Table 4). Initial values of this index in beginning of process were from 12.08 to 12.25 and the effect of irradiation in reducing the chroma change was more than dryer temperature. Hence, irradiation doses deminished the intensity of color change. Temperature did not show any significant effect on the chroma, as was reported in another study (Wachiraphansakul and Devahastin, 2007).

Hue angle at the beginning of process was between 82° to 83° and at the end of process was between 70° to 78°. Therefore, it can be concluded that the color of mushroom changed from yellow to yellow-red (Hue angle <

90). As shown in Table 4, this index was affected significantly by irradiation doses and drying temperatures ($p < 0.05$). The similar result for mushroom has been reported (Guo et al., 2014).

3.5 Area shrinkage

The results showed that area shrinkage did not change significantly under the high irradiation doses. At the end of drying process, the area shrinkage in drying temperature of 50 ℃ at doses of 0, 1.2, 2.4 and 3.6 kGy was 0.615, 0.610, 0.604 and 0593, respectively (Figure 5). The time of drying for the samples at the same condition was 310, 290, 250 and 190 minutes, respectively (Table 1). The results showed that by increasing the drying temperature, the value of shrinkage increased. The main reason for this result was increasing the rate of dehydration. The similar results for grapes have been reported (Khazaei et al., 2013). In order to reduce the shrinkage in the structure of agricultural products, the relative humidity, rate of dehydration, drying temperature, pretreatment, size and amount of material during drying process need to be controlled (Shen et al., 2015; Shen et al., 2016).

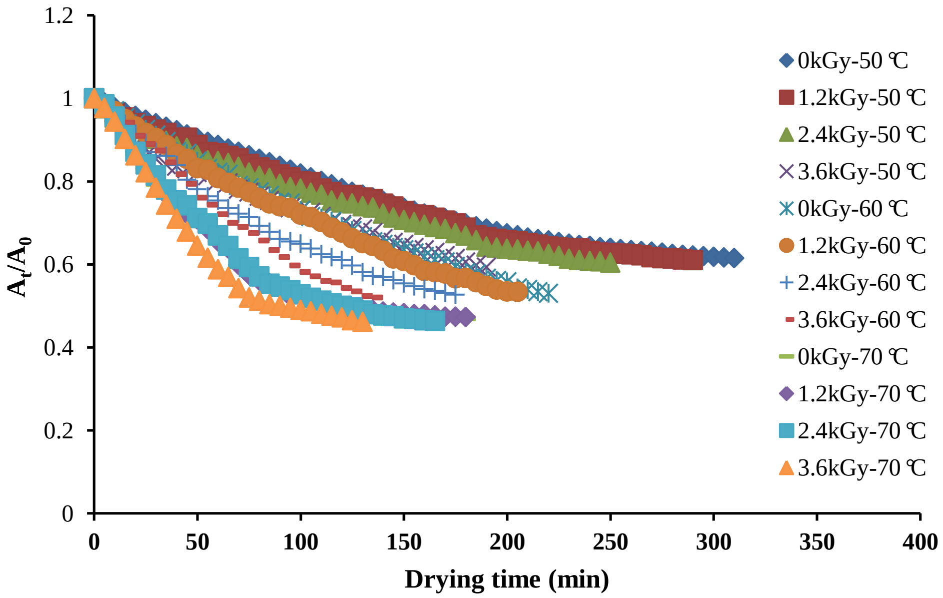


Figure 5 Comparison of the effects of irradiation doses and drying temperatures on area shrinkage

Table 3 The results of modeling for the color indices (L^*, b^* and ΔE) in first order model

		T=50 ℃			T=60 ℃			T=70 ℃		
Dose(kGy)	C	K	C_0	R^2	k	C_0	R^2	k	C_0	R^2
0	L^*	0.0003	85.42	0.98	0.0007	85.21	0.99	0.0009	85.56	0.99
	b^*	-0.0009	12.30	0.98	-0.0014	12.06	0.98	-0.0020	12.27	0.98
	ΔE	-0.0060	-0.133	0.92	-0.0083	2.41	0.91	-0.0105	2.41	0.92
1.2	L^*	0.0004	85.74	0.98	0.0007	85.34	0.99	0.0009	85.84	0.99
	b^*	-0.0009	12.16	0.98	-0.0014	12.07	0.99	-0.0016	12.14	0.99
	ΔE	-0.0066	1.699	0.92	-0.0092	2.08	0.92	-0.0111	2.10	0.92
2.4	L^*	0.0004	85.92	0.97	0.0007	85.88	0.99	0.0009	86.13	0.98
	b^*	-0.0006	11.92	0.99	-0.0009	12.00	0.99	-0.0011	11.98	0.99
	ΔE	-0.0083	1.28	0.94	-0.0114	1.68	0.95	-0.0129	1.68	0.93

3.6	$L*$	0.0004	86.04	0.94	0.0007	85.79	0.98	0.0009	86.07	0.98
	$b*$	-0.0004	11.98	0.99	-0.0006	12.03	0.99	-0.0008	12.04	0.99
	ΔE	-0.0115	0.961	0.98	-0.0153	1.18	0.95	-0.0173	1.21	0.94

Table 4 Comparison of the color values of mushroom slices pretreated under various irradiation doses and dried at different temperatures

Dose (kGy)	Tempreture (℃)	ΔE	BI	Chroma	Hue Angle
0	50	10.22^b	26.89^f	16.47^{cd}	76.98^f
	60	12.82^d	29.24^h	17.04^d	76.05^e
	70	13.86^e	31.15^i	17.72^d	74.95^d
1.2	50	10.13^b	25.89^e	15.95^c	77.14^f
	60	12.14^d	27.80^g	16.36^c	75.52^{de}
	70	13.39^e	29.58^h	16.89^{cd}	73.88^c
2.4	50	8.93^a	22.94^b	14.31^b	75.26^d
	60	11.12^c	24.56^d	14.70^b	73.52^c
	70	12.20^d	26.18^{ef}	15.18^{bc}	72.01^b
3.6	50	8.28^a	21.33^a	13.53^a	75.01^d
	60	8.34^a	22.27^b	13.84^a	71.77^b
	70	10.05^b	23.82^c	14.25^{ab}	70.92^a

Note: In each column, different small letters represent significant differences (5% level).

4 Conclusion

The high correlation coefficient for color indices ($L*$, $a*$ and $b*$) between data obtained from the colorimeter and image processing showed that this method was capable to measure the color change precisely. Investigation of color change for the pretreated mushrooms during drying process showed that gamma irradiation, as a non-destructive method, was effective in preservation the color indices. By increasing the irradiation dose and reducing the drying temperature, the total color difference and browning index decreased. Irradiation was effective in reducing the change of chroma, but effect of drying temperature was insignificant. The change of hue angle showed that the color mushrooms changes from yellow to yellow-red. Zero order model was found useful for describing the color change ($L*$, $b*$ and ΔE) as a function of drying times. The increase of irradiation dose, although reduced drying time and slightly increased area shrinkage, but the negative effect of temperature on the area shrinkage was significant.

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