Comparative analyses of three pretreatments on color of kiwifruits during hot air drying

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Abstract: Color is one of the most important quality attributes for agricultural products due to its great influence on consumers' appetite. Effects of pretreatments, including blanching with hot water, osmosis with sucrose solution, and soaking with ascorbic acid solution on the color of kiwifruit slices were investigated during hot air drying, and three models (i.e. zero-order, first-order and Weibull models) were used to describe the color change kinetics of soaking samples. The results illustrated that color parameters (L^*, a^* and b^*) of dried kiwifruit slices were improved significantly by immersing in sucrose solution or ascorbic acid solution before drying, whereas immersing in hot water for long time led to severe color deterioration. For un-pretreated samples, the Weibull model was the best to describe change kinetics of L^* and a^* values with R^2 =0.974 and 0.996, respectively, while the zero-order model was best for the changes of ΔE value (R^2 =0.996). For samples immersed in 1% ascorbic acid solution for 15 min, change kinetics of L^* and ΔE values were best fitted to zero-order models with R^2 =0.988 and 0.972, respectively. ΔE of dried samples without pretreatment was 12.55, but decreased by approximately 16.33% when samples soaked in 1% ascorbic acid solution for 15 min before drying.

Keywords: color, computer vision system, kinetic model, ascorbic acid, sucrose
DOI: 10.25165/j.ijabe.20201302.5489

Citation: Xu R Z, Zhou X, Wang S J. Comparative analyses of three pretreatments on color of kiwifruits during hot air drying. Int J Agric & Biol Eng, 2020; 13(2): 228–234.

1 Introduction

Kiwifruit is one of the most popular fruits worldwide due to its high content of chlorophyll, ascorbic acid and phytochemicals[1]. Recently, the production of kiwifruits increases rapidly owing to the development of new cultivation and picking technology[2,3]. Fresh kiwifruits decompose easily even at refrigerated storage conditions due to high moisture content[4]. Thus, processing after postharvest is important to extend the shelf-life of kiwifruits.

Drying is a traditional processing technology to extend the shelf-life of foods since it can slow down the growth of microorganisms and inhibit activity of enzymes by reducing the water content to a safe level[5,6]. Among many drying technologies, hot air drying is one of the most common dehydration methods in fruits and vegetables processes since the system could be easily constructed and operated with low cost[7]. However, due to poor heat and mass transfer during the falling rate period, hot air drying generally results in undesired product quality[4,8], especially degradation of color, which is one of the most important quality characteristics of foods because it determines the first impact of consumers on a product[9,10].

Pre-treatments, including thermal blanching, osmotic dehydration and sulfuration, are necessary before drying to improve the color of dehydrated fruits and vegetables[4,5]. Sulfides are phased out and replaced by ascorbic acid and citric acid due to adverse effects on human health and environment in food industry[11,12]. Treated by 97℃ hot water for 30 s before drying, the kiwifruit slices had lower value of the total color difference (ΔE) than that of untreated kiwifruit slices[13]. The pretreatment for blanching in 75℃ hot water for 5 min had no effect on improvement of color of dried kiwifruit slices[14]. Improvement of color is affected both by blanching temperature and time before drying. The color of kiwifruits pretreated by osmotic dehydration after infrared drying was closer to that of fresh samples than that of un-pretreated samples[15]. The treatment temperature had significant influence on color degradation in kiwifruits during osmotic process[16], and osmotic concentration and time significantly affected moisture content of kiwifruits[17]. 1% ascorbic acid combined with citric acid is used as anti-browning agent to treat vegetables and fruits before drying process. The treatment dipping in 1% ascorbic acid combined with 0.2% critic acid solution improved significantly L^* of dried apple cubes[12]. The ΔE value of kiwifruits decreased slightly by immersing in 1% ascorbic acid solution (w/w) with pH of 3.8, which may be due to the change of pectin structured cell wall in acidic environment[14].

The information of color change kinetics is essential for improving color of product[18]. Zero-order, first-order and Weibull models have been commonly used to describe the color change kinetics[9]. For example, Dadali et al.[19] studied the influence of the microwave power and spinach amounts on kinetic parameters of zero- and first-order models for color changes during microwave drying. Color change kinetics of kiwifruits might be influenced by different drying methods and hot air temperatures[20,21]. L^*, a^* and b^* change kinetics of red peppers were fitted with Weibull model during hot air drying, illustrating that Weibull model is better to fit the color change of red pepper

Received date: 2019-11-29 **Accepted date:** 2020-02-03
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than zero- and first-order models[22]. Although many studies about the effects of pretreatment on the color changes of fruits and vegetables after hot air drying have been reported, to authors' knowledge so far, few studies have been carried out about the influence of pretreatments on the color change kinetics of kiwifruits during hot air drying.

Therefore, the main objectives of this study were to study the influence of blanching with hot water, osmotic dehydration with sucrose solution and soaking with ascorbic acid solution on L^*, a^* and b^* of dried kiwifruit and to develop the color change kinetics of soaked kiwifruit in drying process.

2 Materials and methods

2.1 Materials

Kiwifruits (*Actinidia deliciosa cv* Hayward) were purchased from a local supermarket in Yangling, Shaanxi, China and stored in a refrigerator (BD/BC-297KMQ, Midea Group Co., Ltd., Hefei, China) at 4.0 ℃±0.5 ℃. The initial moisture content of the fresh kiwifruits was (4.52±0.39) kg/kg in dry basis (d.b.), and moisture contents of all samples were determined using a vacuum oven method by drying to constant weight at 70 ℃[23]. Soluble solids content of (12.8±0.5) °Brix was obtained by a digital hand-held refractometer (PAL-1, ATAGO Co. Ltd., Atago, Japan). Distilled water was used in all experiments. Sucrose (food grade) was purchased in a local supermarket. Ascorbic acid and citric acid were purchased from Guanghua Sci-Tech Co., Ltd., Guangzhou, Guangdong, China. Prior to each experiment, the samples were taken out of the refrigerator, sealed in the polyethylene bag and placed in an incubator (BSC-150, Haixin Instrument & Equipment Co., Ltd., Shanghai, China) at 25 ℃ for 12 h. Then the hand peeled kiwifruits were cut perpendicularly to the fruit axis into slices with (43.0±1.2) mm diameter and (8.0±0.4) mm thickness by a slicer. Slice samples of (85±3) g were used for each experiment.

2.2 Pretreatment processes

2.2.1 Hot water blanching pretreatment

Kiwifruit slices were immersed into hot water in a thermostatically controlled water bath (SC-15, Ningbo Scient Biotechnology Co., Ltd., Ningbo, China). According to previous studies[13,14] and preliminary experiment results, the blanching temperatures and times were determined as 70 ℃, 80 ℃ and 90 ℃ for 1 min, 2 min and 3 min, respectively. After blanching, the kiwifruit slices were removed from hot water and immediately put into 7.0 ℃±0.5 ℃ cold water in a low temperature thermostatic bath (DC-1006, Zhongxingweiye Instrument Co., Ltd, Beijing, China) to prevent excessive blanching. During cooling, the real-time temperature at the center of the kiwifruit slice was monitored by a type T thermocouple (HH-25TC, OMEGA Engineering Inc, Stamford, Connecticut, USA). When the temperature at center of the sample dropped to 25 ℃, the sample was then removed from cold water and drained over a filter paper to remove the surface water.

2.2.2 Osmotic dehydration pretreatment

Parameters of osmotic dehydration were selected according to Cao et al.[24] The samples were immersed in the sucrose solution with three concentration levels, i.e. 30%, 45% and 60% (kg/L, w/v) for 60 min, 120 min and 180 min and stirred every half an hour. A ratio of 1:10 (w/w) of kiwifruit samples to the osmotic solution was used[24]. After the osmotic dehydration treatment, the kiwifruit slices were taken out of the solution, rinsing the slice surface with distilled water and surface water was removed with filter paper.

2.2.3 Soaking pretreatment

According to the soaking method reported by Nadian et al.[14], the kiwifruit slices were immersed in the solutions containing 1% (kg/L, w/v) ascorbic acid solution with three concentrations (0.0, 0.1% and 0.2% (kg/L, w/v)) of citric acid for different time (5 min, 10 min and 15 min) at 25 ℃, and a ratio of 1:10 (w/w) of kiwifruit samples to the acid solution was used. These three concentrations of citric acid corresponded to 2.96, 2.87 and 2.78 of pH, respectively, determined using a pH meter (PHS-25, INSEA Instrument Co., Ltd., Shanghai, China), after calibration. After soaking, samples were taken out of the solution and adhering water was removed with filter paper.

2.3 Hot air drying

After pretreatments, samples were put in a polypropylene container with holes on sides and bottom walls, and hot air drying was carried out in a hot air drying system (DGG-9203A, Precision & Scientific Instrument Co., Ltd., Shanghai, China) at 60 ℃ and an air velocity of 1.0 m/s measured by a rotating vane anemometer (LCA 6000, AIRFLOW Instrumentation, Buckingham-215 Shire, UK). The drying process was not stopped until the moisture content of the product dropped to 0.25 kg/kg (d.b.). To calculate the moisture content during drying, samples were taken out of the drying chamber every one hour and measured by a digital balance (PTX-FA210, Huazhi Scientific Instrument, Co., Ltd., Fuzhou, China) with a precision of 0.01 g.

2.4 Evaluation of color

A computer vision system (CVS) (Figure 1) was used to obtain, store and analyze the surface color of kiwifruit slices. The CVS included a shooting tent (41 cm×30 cm×30 cm) with two photography lamps (LS235 5500K), a Cannon EOS 600D digital camera and a Lenovo Y471A notebook computer, and the detailed descriptions and procedures can be found in another study[25]. The required CIE LAB (L^*, a^* and b^*) values were obtained from Photoshop (L, a and b) using the following equations[26]:

$$L^* = \frac{L}{2.5} \tag{1}$$

$$a^* = \frac{240a}{255} - 120 \tag{2}$$

$$b^* = \frac{240b}{255} - 120 \tag{3}$$

Furthermore, in CIE LAB system, the value of L^* varies from 0 (black) to 100 (white). a^* and b^* values both ranges from –60 to +60, also from $-a$ (green) to $+a$ (red) and from $-b$ (blue) to $+b$ (yellow), respectively. The total color difference (ΔE) was calculated from the L^*, a^* and b^* and used to describe the color change:

$$\Delta E = \sqrt{(L_f^* - L_t^*)^2 - (a_f^* - a_t^*)^2 - (b_f^* - b_t^*)^2} \tag{4}$$

where, subscripts "f" and "t" refer to the color reading of fresh and treated kiwifruits for the time of t, min, respectively. A larger ΔE stands for a larger color change from the fresh kiwifruit.

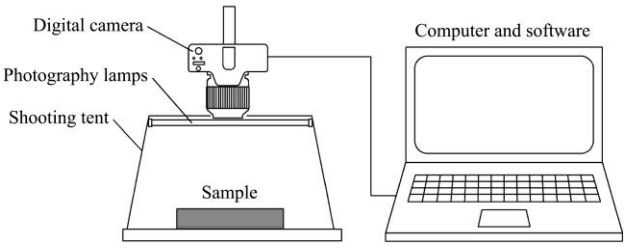


Figure 1 Schematic view of computer vision system (adapted from Hou et al.[23])

2.5 Kinetic models

The zero-order, first-order and Weibull models have been used to evaluate the color degradation kinetics of various foods during thermal processes, and are described below:

Zero–order model:

$$C_t = C_0 \pm k\,t \tag{5}$$

First–order model:

$$C_t = C_0 \exp(\pm k\,t) \tag{6}$$

Weibull model:

$$C_t = C_0 \exp(-\alpha \times t^{\beta}) \tag{7}$$

where, (+) and (–) indicate formation and degradation of any quality parameters, respectively; C_0 is the value of surface color parameters before drying (L^*, a^* or ΔE); C_t is the corresponding value at drying time t, min, k is the rate constant, min^{-1}; α is the scale parameter, $min^{-\beta}$, and β is the shape factor.

The coefficient of determination (R^2) and root mean square error (*RMSE*) were used to select the best fit of the tested model to experimental data. The higher R^2 value and lower *RMSE*, the better the model was taken to fit.

$$RMSE = \sqrt{\frac{\left[\sum_{i}^{N}(C_{pre,i} - C_{exp,i})^2\right]}{N}} \tag{8}$$

where, $C_{pre,i}$ is the ith predicted value; $C_{exp,i}$ is the ith experimental value, and N is the total number of observations.

2.6 Statistical analysis

Test results were expressed as average ± standard deviations of all observations from the three replicates. The significance was evaluated using a Duncan test with a 95% confidence interval (p<0.05). The non-linear regression analysis was carried out using statistical analysis software SPSS 16.0 version (SPSS Ins., Chicago, IL, USA) with the coefficient of determination (R^2) and the root mean square error (*RMSE*), which were used to evaluate the fitness of models.

3 Results and discussion

3.1 Effects of pretreatment methods on color of dried kiwifruit

The color parameters of blanched kiwifruits after dried at hot air (60 ℃) are presented in Table 1. The results showed significant effect of blanching temperature and time on the color of dried kiwifruits (p<0.05). With increasing temperature and time of hot water blanching pretreatment (BP), the values of brightness (L^*) of dried kiwifruits generally decreased, owing to non-enzymatic browning. Similar changes are reported in onion slices by Ren et al.[27]. During short time blanching treatments, increased intra-cellular spaces, inter-cellular channels and the formation of new pathways through the structure of samples can lead to high drying rate of samples[14,27]. Browning of ascorbic acid and gelatinization of carbohydrates occurred in samples during long time blanching process, resulting in the formation of melanin and longer drying time, respectively[14,27]. Under the condition of 3 min hot water blanching, there were significant differences (p<0.05) in both a^* and b^* between 70 ℃ and 90 ℃ hot water treated samples. This may be because the natural pigments, such as chlorophylls (green), xanthophylls and β-carotene (yellow), degraded and diffused to the hot water from kiwifruits during BP with the high temperature and long time[28]. Similar results are also reported for other fruits. For example, blanched cherry tomatoes have the larger Δa^* and Δb^* than the un-blanched samples after drying[29]. Additionally, dried kiwifruit slices pretreated with BP for short time had lower value of ΔE than un-pretreated dried samples, which had an agreement with the result of Nadian et al.[14].

Table 1 Means and standard deviations (n=3) of color parameters (L^*, a^* and b^*) and total color difference (ΔE) of blanched kiwifruit slices treated by hot air drying at a temperature of 60 ℃ and an air velocity of 1.0 m/s until moisture content of samples dropped to 0.25 (kg/kg, d.b.)

Temperature /℃	Time /min	L^*	a^*	b^*	ΔE
Control		31.67±0.62ab[&]	–0.32±0.32bc	27.44±0.37a	12.55±0.52cd
70	1	33.29±0.56a	–0.82±0.28c	26.94±0.86ab	11.39±0.58d
	2	30.89±0.81bc	–0.42±0.44bc	24.42±0.93cd	13.89±0.55bc
	3	29.60±0.44c	0.44±0.26b	24.17±0.38cd	15.38±0.96b
80	1	32.76±0.02ab	–0.21±0.23bc	26.77±0.41ab	12.04±0.55cd
	2	29.29±0.41c	0.34±0.24b	25.13±0.79bc	14.79±0.20b
	3	29.44±0.76c	0.38±0.22b	22.35±0.47de	15.70±0.39b
90	1	30.02±0.44c	–0.03±0.09bc	25.04±0.82bc	14.16±0.63bc
	2	25.10±0.57d	0.36±0.11b	24.91±0.50bc	18.03±0.49a
	3	26.03±0.76d	1.38±0.26a	21.43±0.73e	19.71±0.39a

Note: [&] Different lowercase letters within a column indicate that means are significantly different at p<0.05 among different blanching pretreatments.

The average values and standard deviations of L^*, a^*, b^* and ΔE for kiwifruit slices dried at hot air with osmotic dehydration pretreatment (OP) are listed in Table 2. The results illustrated that the dried kiwifruit pretreated with OP had lower a^* and ΔE values, and higher L^* and b^* values. Similar results are also reported by Lyu et al.[15] in which kiwifruit slices were dried by short- and medium-wave infrared radiation with or without osmotic dehydration. Osmotic concentration and time had no significant difference (p>0.05) in both a^* and b^* of dried kiwifruits, which may be due to the loss of pigment during osmotic treatment[5] and different drying time. At 45% and 60% concentrations, the ΔE values of the samples treated for 3 h were significantly different (p<0.05) from the control.

Table 2 Means and standard deviations (n=3) of color parameters (L^*, a^* and b^*) and total color difference (ΔE) of kiwifruit slices treated by hot air drying at a temperature of 60 ℃ and an air velocity of 1.0 m/s until moisture content of samples dropped to 0.25 (kg/kg, d.b.) with osmotic pretreatments

Concentration /(w/v)	Time /min	L^*	a^*	b^*	ΔE
Control		31.67±0.62b[&]	–0.32±0.32ab	27.44±0.37abc	12.55±0.52a
30%	60	33.47±0.81ab	–0.43±0.52ab	26.51±0.17bc	12.09±0.61ab
	120	32.53±0.65ab	–0.66±0.09b	28.22±0.15a	11.39±0.30ab
	180	33.92±0.81a	–0.85±0.27b	27.68±0.82abc	11.27±0.19ab
45%	60	32.26±0.96ab	0.59±0.04a	26.27±0.34c	12.27±0.31a
	120	32.38±0.75ab	–0.06±0.07ab	28.03±0.83ab	11.84±0.05ab
	180	33.48±0.30ab	–0.64±0.45b	27.12±0.28abc	10.94±0.68b
60%	60	33.98±0.12a	0.04±0.42ab	27.94±0.31ab	12.16±0.13ab
	120	31.33±0.12b	–0.78±0.33b	28.07±0.65ab	11.22±0.45ab
	180	34.07±0.58a	–1.06±0.37b	26.20±0.30c	10.78±0.24b

Note: [&] Different lowercase letters within a column indicate that means are significantly different at p<0.05 among different sucrose solution pretreatments.

The values of color parameters of kiwifruits treated by hot air drying with soaking pretreatment (SP) are listed in Table 3. SP enhanced color of dehydrated kiwifruits significantly (p<0.05). Compared with the control, soaked kiwifruit after drying had

higher L^* value (from 32.22 to 34.13) and b^*value (from 27.22 to 31.86), and lower ΔE value (from 10.50 to 12.42) and a^* value (from –1.22 to –0.10). Improvement of L^* by SP is also reported by Nadian et al.[30] and Zhu et al.[12]. For example, apple slices dipped in ascorbic acid solution combined with citric acid had lower browning value than the untreated sample during hot air drying[30]. Also, for apple cubes, longer dipping time and higher concentration of citric acid resulted in higher L^* and lower reduction of L^*, respectively[12]. This may be because the POD activities are reduced and thus browning reactions are reduced at acidic environment[5]. The lowest a^* and highest b^* values were observed in kiwifruits treated by solution combined 1% ascorbic acid and 0.1% citric acid with 15 min due to the best penetration as result of long dipping time and degradation of chlorophylls in acidic environment[12,31]. Additionally, SP samples after drying had lower ΔE value than control ones, which is different from the result reported by Nadian et al.[14] This may be due to the lower pH (2.96) of acid solution and the lower temperature (60 ℃) of hot air in this study as compared to the solution pH (3.80) and the treatment temperature (70 ℃) in Nadian et al.[14].

Table 3 Means and standard deviations (n=3) of color parameters (L^*, a^* and b^*) and total color difference (ΔE) of kiwifruit slices pretreated with solution of ascorbic acid combined with citric acid treated by hot air drying at a temperature of 60 ℃ and an air velocity of 1.0 m/s until moisture content of samples dropped to 0.25 (kg/kg, d.b.)

Solution	Soaking time/min	L^*	a^*	b^*	ΔE
Control		31.67±0.62b[&]	–0.32±0.32ab	27.44±0.37cd	12.55±0.52a
A0[#]	5	32.85±0.84ab	–0.35±0.20ab	30.28±0.49ab	11.62±0.18abc
	10	32.62±0.93ab	–0.42±0.06ab	28.64±0.28bcd	11.33±0.20abc
	15	33.96±0.44a	–0.92±0.10bc	29.30±0.56b	10.50±0.27c
A1	5	32.51±0.26ab	–0.28±0.10ab	29.03±0.47bc	11.34±0.13abc
	10	32.22±0.49ab	–0.17±0.28a	28.49±0.71bcd	11.68±0.66abc
	15	32.16±0.76ab	–1.22±0.19c	31.86±0.23a	10.68±0.28bc
A2	5	32.33±0.32ab	–0.10±0.02a	27.22±0.69d	12.42±0.18a
	10	34.13±0.62a	–0.52±0.09ab	29.05±0.63bc	10.83±0.41bc
	15	32.96±0.56ab	–0.12±0.28a	28.50±0.52bcd	11.83±0.55ab

Note: [&] Different lowercase letters within a column indicate that means are significantly different at P<0.05 among different soaking pretreatments.

[#]A0: 1% ascorbic acid and 0.0% citric acid, A1: 1% ascorbic acid and 0.1% citric acid, and A2: 1% ascorbic acid and 0.2% citric acid.

The acid treatment was the best pretreatment to improve color, followed by osmotic treatment, and the worst was blanching treatment according to ΔE of dried samples. This was probably because acid treatment reduced the peroxidase activity[32] and drying time.

3.2 Effect of pretreatments on drying time

According to the smallest ΔE of dried samples in above study, blanching in 70 ℃ hot water for 1 min, osmosis in 60% sucrose solution for 180 min and soaking in 1% ascorbic acid solution for 15 min were selected for subsequent comparison. Figure 2 show the change of moisture content of samples after different pretreatment during drying. The drying times of all pretreated samples were shorter than those from the control, and the shortest was that treated by blanching with hot water, then osmotic treatment with sucrose solution and last soaking treatment with ascorbic acid solution. The effect of pre-treatments on drying time has also been reported by others[13,15,33]. Movement of water from internal tissue to the external surface is accelerated after blanching due to increased intra-cellular spaces, inter-cellular channels and the formation of new pathways through the structure[14]. The moisture reduction of soaked samples was slightly faster than that of control due to loosens of pectin in acidic environment[34].

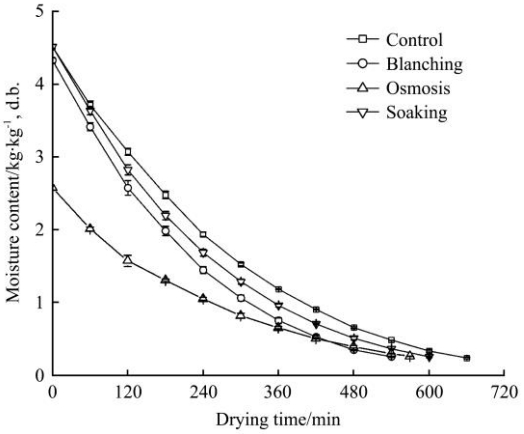
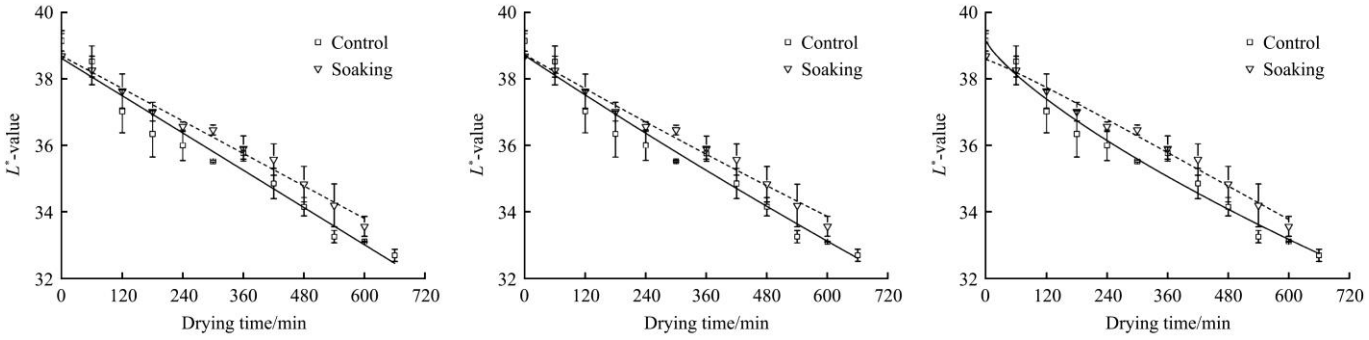


Figure 2 Changes of moisture contents in samples with drying time at 60 ℃ hot air after three pretreatments

3.3 Color changes

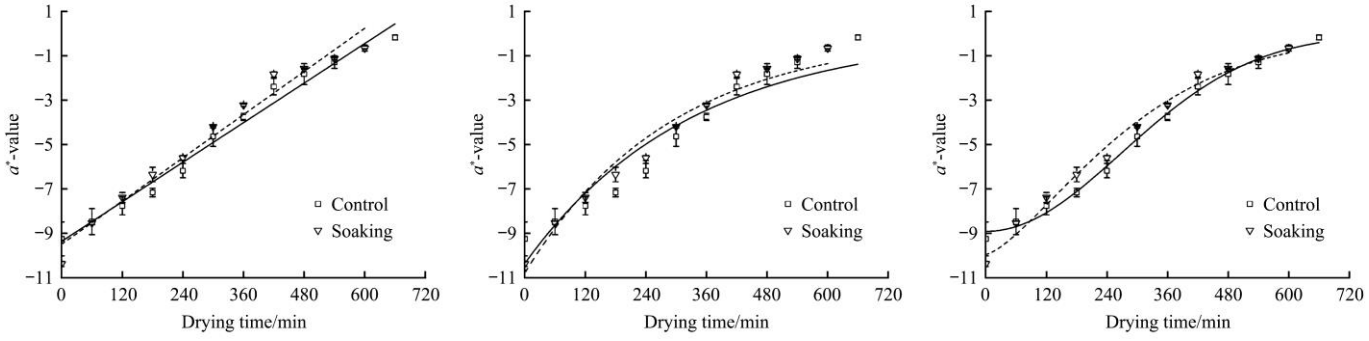
Based on the above study, the color changes in the samples pretreated by 1% ascorbic acid for 15 min was minimal. Therefore, this pretreatment condition was selected for the subsequent experiments. The change of b^* value in this study was not analyzed during drying due to the negligible change of b^* value. Similar consideration is taken for color measurements in pomegranate juice[35], chestnut kernel[25] and strawberry juice[36]. Figures 3-5 show the values of L^*, a^* and ΔE, respectively, of kiwifruit un-pretreated or pretreated by 1% ascorbic acid solution for 15 min during hot air drying (60 ℃).

As show in Figure 3, the L^* values (brightness / darkness) of untreated or treated samples decrease, which illustrated that the samples were turning darker due to browning and formation of dark compounds. In the earlier stage of the hot air drying process (60 ℃), temperature of kiwifruit slices increased but not reached the temperature (50 ℃) required to inactivate polyphenol oxidase, which could lead to the improvement of polyphenol oxidase enzyme activity[14,31]. As the drying progressed, the reaction substrates concentration increased and the Maillard reaction accelerated[37]. Compared with the control during drying, pretreated samples had higher L^* value due to lower pH value and PPO activity of the samples[5]. The increase of a^* value (redness / greenness) for untreated or pretreated samples in drying process illustrated that the green of the kiwifruit faded (Figure 4) because of chlorophyll degradation of kiwifruits. The samples treated by 1% ascorbic acid for 15 min had lower a^* values (–10.48) compared with that (–9.31) of control before drying, but in the late drying stage, opposite phenomenon was obtained. These may because ascorbic acid hinders the conversion of chlorophylls to pheophytins[31] and low pH environment has an adverse effect on retention of chlorophyll at high temperatures[38]. According to Figure 5, a color change occurred in treated samples before drying, due to effect of pretreatment on the color of kiwifruits. During the drying process, similar changes for L^*, a^* and ΔE are also reported by other studies, such as kiwifruit[4] and green bean[39], due to pigment destruction, and ascorbic, enzymatic and Maillard browning[14,20].



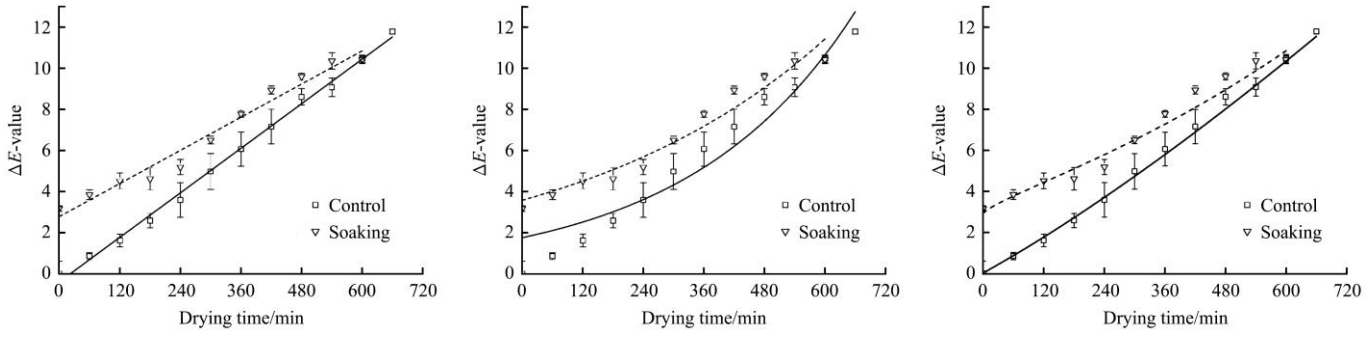
a. Zero order model b. First order model c. Weibull model

Figure 3 Kinetics of change of the L^* value of kiwifruit slices untreated or treated by soaking in 1% ascorbic acid for 15 min during hot air drying for zero order, first order and Weibull models



a. Zero order model b. First order model c. Weibull model

Figure 4 Kinetics of change of the a^* value of kiwifruit slices untreated or treated by soaking in 1% ascorbic acid for 15 min during hot air drying for zero order, first order and Weibull models



a. Zero order model b. First order model c. Weibull model

Figure 5 Kinetics of change of the ΔE value of kiwifruit slices untreated or treated by soaking in 1% ascorbic acid for 15 min during hot air drying for zero order, first order and Weibull models

3.4 Color kinetics

Parameters of zero-order, first-order and Weibull models are presented in Table 4. For control, Weibull model showed the best fit to the changes of L^* (R^2 = 0.974 and *RMSE* = 0.316) and a* (R^2 = 0.996 and *RMSE* = 0.198) and zero-order model was the best model to fit ΔE values (R^2 = 0.996 and *RMSE* = 0.237). On the other hand, zero-order and first-order models slightly worse fitted the experimental data for L^* (R^2 = 0.963 and *RMSE* = 0.381) and the changes of a^* (R^2 = 0.928 and *RMSE* = 0.835) and ΔE (R^2 = 0.940 and *RMSE* = 0.920), respectively. Compared with another study[20], zero-order model has lower constant k for L^*, a^* and ΔE (9.34×10^{-3} min^{-1}, 14.86×10^{-3} min^{-1} and 18.07×10^{-3} min^{-1}, respectively), probably due to higher sample thickness (8 mm) and lower air velocity (1 m/s) as compared to the previous study (5 mm and 1.28 m/s, respectively). Zero-order model was best to fit changes of L^* (R^2 = 0.988 and *RMSE* = 0.169) and ΔE (R^2 = 0.972 and *RMSE* = 0.431), meanwhile Weibull model was best for describing the change of a^* (R^2 = 0.989 and *RMSE* = 0.327) of samples treated by 1% ascorbic acid with 15 min. On the other hand, first-order model slightly worse fitted changes of L^* (R^2 = 0.986 and *RMSE* = 0.182), a^* (R^2 = 0.972 and *RMSE* = 0.525) and ΔE (R^2 = 0.957 and *RMSE* = 0.534) during drying. The results indicated that Weibull model best described experiment data of a^*, which is similar to the study on red pepper reported by Yang et al.[39] ΔE change was described best by the zero-order model, which is in agreement with studies on kiwifruits[20] and spinach[19]. Additionally, the scale parameter (α) of treated samples was lower than that of control for L^* in Weibull model, and opposite phenomenon obtained for a^*, illustrating that treatment with 1% ascorbic acid with 15 min slowed down the browning reactions and accelerated chlorophylls degradation in kiwifruit during drying.

Table 4 Kinetic parameters of color changes of kiwifruit slices untreated or treated with 1% ascorbic acid for 15 min estimated from different models

Model		Control			Soaking treatment		
		L^*	a^*	ΔE	L^*	a^*	ΔE
Zero order	C_0	38.61	–9.37	–0.41	38.69	–9.50	2.77
	$k\times10^{-3}$/min^{-1}	–9.34	14.86	18.07	–8.15	16.23	13.45
	R^2	0.963	0.985	0.996	0.988	0.973	0.972
	RMSE	0.381	0.374	0.237	0.169	0.517	0.431
First order	C_0	38.70	–10.37	1.75	38.73	–10.80	3.57
	$k\times10^{-4}$/min^{-1}	–2.64	–30.54	30.09	–2.24	–34.56	19.39
	R^2	0.966	0.928	0.940	0.986	0.972	0.957
	RMSE	0.363	0.835	0.920	0.182	0.525	0.534
Weibull	C_0	39.15	–8.94	1.161×10^{-7}	38.58	–9.96	2.91
	α/min$^{-\beta}$	1.02×10^{-3}	8.22×10^{-6}	-12.23	1.06×10^{-4}	3.05×10^{-4}	–0.014
	β	0.796	1.973	0.063	1.116	1.405	0.710
	R^2	0.974	0.996	0.997	0.988	0.989	0.970
	RMSE	0.316	0.198	0.241	0.170	0.327	0.475

4 Conclusions

The study illustrated that the color of dehydrated kiwifruit slices was affected by pretreatments and the soaking in 1% ascorbic acid solution for 15 min was the best pretreatment to prevent color change during drying compared with blanching and osmotic pretreatments. All pretreatments shortened drying time, and blanching treatment had the shortest drying time, followed by osmotic and soaking treatments. Ascorbic acid pretreatments reduced the rate of changes L^* and ΔE, and accelerated the increase of a^* value. For kiwifruits untreated or treated by 1% ascorbic acid solution, the Weibull model was good to describe the change kinetics of L^* and a^*, and the zero-order model was best for ΔE. In the future, more studies would be carried out on quality (nutrient content, structure, rehydration, etc.) and combining pretreatments with novel drying technology.

Acknowledgements

This research was conducted in the College of Mechanical and Electronic Engineering, Northwest A&F University, and supported by research grants from National Key Research and Development Program of China (2017YFD0400900), National Natural Science Foundation of China (No. 31772031), and Key Laboratory Open Fund (GPCH201703) of Post-Harvest handling of fruits, Ministry of Agriculture. The authors would also like to thank Lihui Zhang, Lixia Hou, Bo Ling, Teng Cheng, and Beihua Zhang for their helps in conducting the experiments and writing this manuscript.

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