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Effect of drying air temperature and chemical pretreatments on quality of dried chilli

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Abstract: The quality of dried chilli (*Capsicum annuum* c.v. Huarou Yon) in terms of color attributes and nutrients was studied using a lab-scale tray dryer in order to reduce the quality loss caused by sun drying. Different drying temperatures from 50-70^{o}C, and a two-stage temperature regime (70^{o}C and 50^{o}C) were used to compare with the sun drying method. A one-temperature regime provided low values of lightness, chroma and hue angle compared to sun drying. The two-stage temperature provided bright–red colored dried chilli. Browning color of dried chilli was observed due to non-enzymatic browning reaction as reducing sugar was decreased. Not only did the Maillard reaction provide a dark-brown color, but thermal degradation and oxidation of total phenolic compounds and ascorbic acid also provided an unacceptable color of dried chilli. A drying temperature of 70^{o}C and a two-stage temperature regime (70^{o}C for 4 hours followed by 50^{o}C) in conjunction with soaking the chilli in different chemical pretreatments were used to promote the color and nutrient preserving capacity. It was found that sodium metabisulfite preserved color stability but not the nutritional compounds chilli was dried at an air temperature of 70^{o}C. Using sodium metabisulfite combined with calcium chloride provided the best color attributes when two-stage temperatures of 70^{o}C and 50^{o}C were used.

Keywords: Chilli, drying, nonenzymatic browning reaction, anti-browning agent

Introduction

The amount of chilli produced in the world is 24 million tonnes (FAO, 2005). The main production areas are located in Asia with 16 million tonnes produced annually (FAO, 2005), of which China produces more than 12 million tonnes. Thailand provides 18,200 tonnes of fresh chillies annually (FAO, 2005). The main production area of chilli in Thailand is located in the northeast, particularly in the southern part of the northeast, namely Ubon Ratchathani and Srisaket provinces. The conventional drying method for chilli is sun drying and this remains the most widely practiced method throughout the producing countries. This method takes more than 5 days, depending on weather conditions, to obtain the required moisture content (4-11% db). Due to this long period of time and direct exposure to air and light, low quality dried chilli is commonly produced. This low quality includes red color fading, development of browning pigment and loss of vitamin C and provitamin A (Osunde and Musa Makama, 2007; Ergüneş and Tarhan, 2006; Ramesh, Wolf *et al*., 2001; Condori *et al*., 2001).

To improve dried chilli quality, some mechanical and solar dryers have been introduced for drying chilli in order to decrease the drying time. (Vega-Gálvez *et*

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al., 2008; Tasirin *et al*., 2007; Kaleemullah and Kailappan, 2005; Doymaz and Pala, 2002; Hossain and Bala, 2002). Most have used air temperatures of between 50-80^{o}C. It has been found that the higher temperatures resulted in reduced drying time and an increase in the effective moisture diffusivity (Kaleemullah and Kailappan, 2005; Di Scala and Crapiste, 2007; Vega *et al*., 2007). However, using high temperatures for drying produces a low quality of chilli, with losses of volatile compounds, nutrients and color (Di Scala and Crapiste, 2008; Kaleemullah and Kailappan, 2006).

The important reactions occurring during drying are enzymatic and nonenzymic browning reaction. Enzymatic browning reaction can be prevented by pretreatment methods, such as blanching and chemical treatment, that bring about inactivated enzyme activity. (Gupta *et al*., 2002; Hossain and Bala, 2002). On the other hand, the nonenzymatic reactions increase in rate at higher temperatures and at intermediate levels of moisture content in the fruit (Manzocco *et al*., 2001; Klieber, 2000; Sigge *et al*., 1999). This reaction is a diffusion-controlled binary reaction between amino acid and reducing sugar, namely the Maillard reaction. It produces color and flavor, which are features of quality change in a food product (Miao and Roos, 2006). Not only do Maillard reactions cause brown or dark colors in dried food product, other reactions may also be involved such as pigment degradation, chemical oxidation of phenols and ascorbic acid (Manzocco *et al.*, 2001; Sigge *et al.*, 1999). A number of researchers have used chemical solutions in order to prevent non-enzyme browning reaction at drying air temperatures of between 55-65^{o}C as a single-temperature regime (Vega-Gálvez *et al.*, 2008, Kaleemullah and Kailappan, 2006; Doymaz and Pala, 2002).

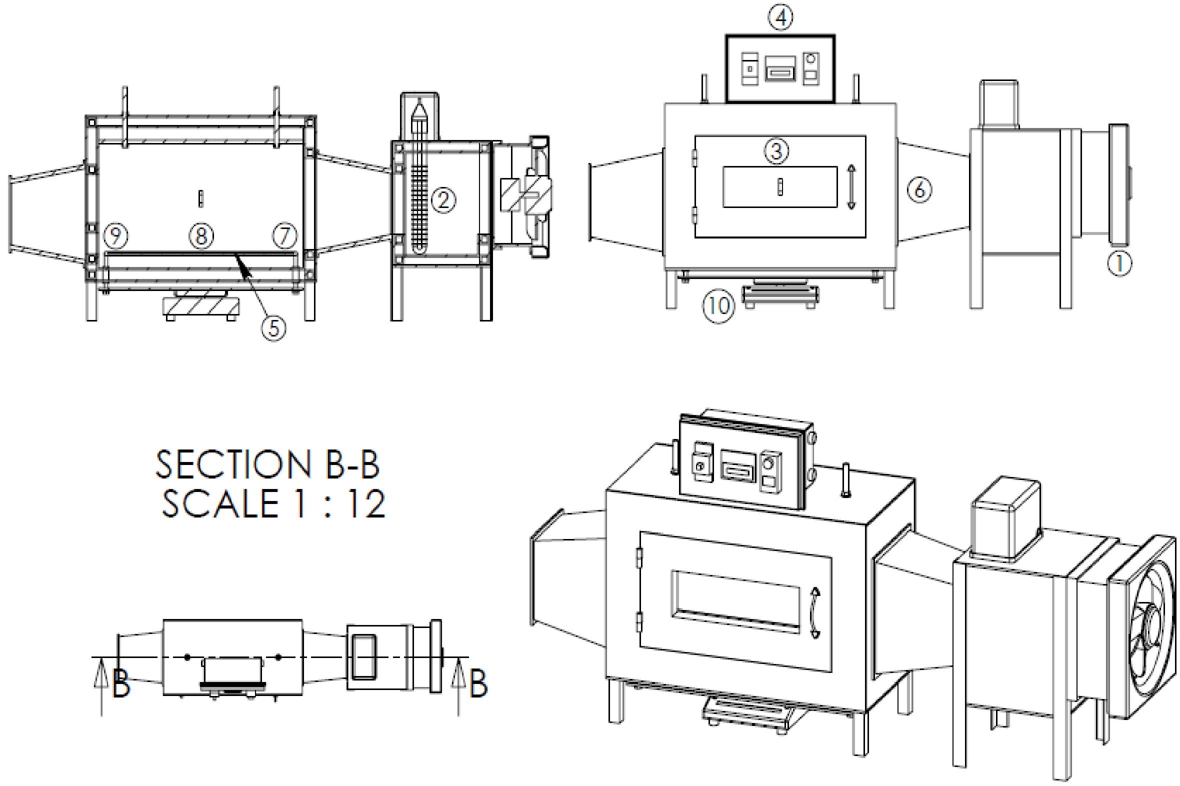
Moreover, it has been found that using stepwise temperatures regimes, such as cyclic or three-stage temperatures, during drying can preserve the color and nutrients of food products (Davidson *et al*., 2003; Ho *et al*., 2002; Chua *et al*., 2000). However, these methods, using drying air temperature of 20-50^{o}C, lead to long drying periods. It can lead to mold growth, particularly in food products with a waxy skin such as tomato or chilli. Furthermore, Klieber (2000) observed a dark-brown red color chilli using both a heat pump dryer (40^{o}C, 20%RH) and a hot air dryer (60^{o}C for 6 hr and then 40^{o}C for 48 hr). Using such a long period of drying can maintain moisture content of chilli at intermediate moisture levels resulting in a brown color. Such color instability and long drying periods have caused concern for chilli drying.

Therefore, the objective of this study was to optimize chilli drying using different drying air temperatures compared to sun drying. Chemical pretreatments were also used to obtain a good quality dried chilli in terms of nutritional values and organoleptic attributes.

Material and Methods

Raw material

Freshly harvested chilli (*Capsicum annuum* c.v. Huarou Yon) was purchased from a local farmer in Srisaket province. Fully ripened chilli of a purely red color was used, having an average moisture content 75.0 ± 0.192%wb, an average diameter of 0.544 ± 0.294 cm and an average length of 5.796 ± 0.681 cm. The fresh chilli was packed in plastic bags and stored in a refrigerator at 7-10^{o}C for 2-3 days before the experiment. The chilli was blanched using hot water at 90^{o}C for 3 minutes (Gupta *et al.*, 2002), and then cooled in cold water and drained on a perforated tray before the experiment.



1-Fan; 2-Electric-heaters; 3-Drying chamber; 4-Controller; 5-Drying tray
6-Temperature probe; 7,8,9- Thermocouples; 10-Digital balance

Figure 1. A schematic diagram of lab-scale tray dryer

Drying methods

Sun drying

Sun drying was conducted at Ubon Ratchathani University by spreading freshly-blanched chilli on a stainless-steel tray in a single layer and exposed directly to sunlight. The temperature of this sun drying method, between March and April 2008, was between 26-53^{o}C and relative humidity was 15-69% as measured by a temperature/relative humidity logger (HOBO, Model H14-001). The temperature and humidity probe was placed on an empty tray besides a tray of chilli. The sun drying method took 3-5 days to obtain the required moisture content (9-11%db) depending on weather conditions. This method was conducted for 8 hr per day, starting at 08.30 a.m. and finishing at 16.30 p.m. Between 450-500 g of chilli was processed for each replication.

Mechanical drying

A laboratory tray dryer with a chamber of 30×60×40 cm and one tray (20×50 cm) was used to dry chilli. The temperature of the dryer was controlled by a temperature controller with a magnetic switch and a voltage regulator adjusting for between 0-260V. The drying air was heated using 4 electric 1.4 kW-heaters. The temperature of inlet air was measured by a temperature probe at the end of duct before entering the drying chamber. A schematic diagram of the tray dryer is shown in Figure 1. The drying air temperatures varied between 50°, 60°, and 70°C recorded by the data logger (PRESICA 2002) and measured by a thermocouple type T, which was inside the chamber at 3 positions (the front, the middle and the end of the tray). The variations in the drying air temperature were between 0.6-2.6 °C. Two-stage temperature was obtained from the preliminary test, which was 70 ± 1°C for 4 hours, at which moisture content of product was less than intermediate moisture levels (a_w ‹ 0.75), and followed by 50±0.4°C until the required moisture content was reached. The air velocity was controlled at 1.34 ± 0.88 m/s (maximum capacity) and measured in nine positions in the chamber by a vane anemometer (DIGICON, Model DA-43) without humidity control. An approximate drying time was calculated, using the Page model obtained from Phomkong, Dasook, Thammarak & Ekpong (2007), in order to obtain the required moisture content. The blanched chilli to be dried was spread on a tray in a rectangular grid as a single layer. The experiment was carried out by using 450-500 g of chilli for each replication.

Chemical pretreatments

The blanched chilli was soaked in different chemical solutions obtained from the literature data as follows: (a) 0.3 % (w/w) sodium metabisulfite (NaMS) (Vega-Gálvez *et al*., 2008); (b) 1% (w/w) ascorbic acid (Son *et al*., 2001) ; (c) 0.3 % (w/w) sodium metabisulfite (NaMS) combined with 1 % (w/w) citric acid (modified from Vega-Gálvez *et al*., 2008 and Son *et al*., 2001); (d) 0.3 % (w/w) sodium metabisulfite (NaMS) combined with 1 % (w/w) calcium chloride ($CaCl_2$) (modified from Vega-Gálvez *et al*., 2008 and Davoodi *et al*., 2007); and (e) freshly-blanched chilli without soaking was used as a control sample. The soaking process was controlled at a temperature of 25 ± 1°C for 10 minutes using a mass ratio between the chilli and chemical solution of 450-500 g: 2 litres.

Determination of moisture content and water activity (a_w)

The AOAC method (AOAC, 1990) was used for determining moisture content using the hot air oven at temperatures of 103-105°C (BINDER, Model FED240-M). Water activity of the chilli was measured using a Thermoconstanter (Novasina, Model PS200 S/N 9809020) calibrated standard sample with a known value (Range 0.11-0.99). The experimental data was obtained using 3 replications.

Color measurements

Surface color measurement was conducted using the L* a* b* system (Universal HunterLab, Model 45/0 S/N CX-0413), calibrated to a standard white tile (L*=91.7, a*=-1.16, b*=1.06). L* corresponds to lightness, a* represents red (+)/green (-) and b* refers to yellow (+)/blue (-). Ten measurements were conducted in each treatment using 5 chilli pods per one measurement. Chroma and Hue angle were suggested to be more practical measures of color (McGuire, 1992).

Reducing sugar analysis

Reducing sugar was analyzed using the Nelson-Somogyi method, which is suitable for food with low reducing sugar (Low, 1994). The concentration of reducing sugar was obtained using a spectrophotometer at 520 nm and a standard curve of glucose at 0-200 µg/ml was used. The method of extraction followed the Lane-Eynon method (AOAC, 1990) using 1 g of chilli. Three replications were conducted.

Ascorbic acid analysis

L-ascorbic acid was analyzed using the 2,6-dichlorophenol indohenol titrimetric method (AOAC, 1990). Five grams of both fresh and dried chilli were mixed with 5% dichloroacetic acid. In addition, 0.1 mg/ml of ascorbic acid solution was used as the standard. The analysis was conducted in three replications.

Total phenolic compounds analysis

Total phenolic compounds were determined using the Folin-Ciocalteau reagent and gallic acid as a standard (Slinkard and Singleton, 1977). The extracted solution was obtained using 0.2 g of chilli flesh mixed with 80% methanol at 200 rpm for 2 hours by using a shaking bath (GFL, Model 1083) at room temperature and then centrifuged at 1500 rpm for 20 minutes controlled at 25°C by using a refrigerated centrifuge (Universal, Model 32R). This was followed by mixing 2 ml of the extract with 10 ml Folin-Ciocalteau reagent before placing these in a dark cabinet for 1-8 minutes. After adding 8 ml of 7.5% Na_2CO_3, the mixture was allowed to stand at room temperature for 2 hours before measuring the absorbance at 765 nm. Triplicate measurements were conducted for all sample treatments. The results were expressed as mg gallic acid/ 100 g dried chilli.

Experimental Design

The effects of the drying air temperatures and chemical pretreatment methods were conducted using Randomized Completed Design (RCD) with three replications. In the drying air temperature study, there were five treatments (sun drying, 50°C, 60°C, 70°C, 70°C + 50°C and fresh chilli) and three replications. In the chemical pretreatment study, there were six treatments (fresh chilli, fresh blanched chilli, 0.3% NaMS, 1% ascorbic acid, 0.3% NaMS with 1% citric acid, 0.3% NaMS with 1% $CalCl_2$) and three replications. ANOVA analysis using SPSS V.11.5 (Trial version) was used to evaluate variances. The least-significant difference test was applied for multiple comparisons at the 95% confidence level.

Results and Discussion

Effect of drying air temperature on chilli quality

Dried chilli prepared from fresh-blanch chilli without chemical pretreatment, using different drying air temperatures, were processed and compared to sun dried chilli. The moisture content of chilli obtained from the different conditions using the AOAC method (AOAC, 1990) were 9.7-11.2% db and water activities were 0.42-0.48. From Figure 2, a lower value of lightness (L*) of dried chilli using drying air temperatures of 50°, 60°, 70°C was observed compared with the sun drying method ($P<0.05$). However, the two-stage drying method significantly improved the lightness of dried chilli compared to other drying method, and this method did not significantly differ from the sun drying method. Nevertheless, different drying air temperatures provided chroma between 26.6-29.6 and these values did not significantly differ from the sun drying method ($P>0.05$). On the other hand, the highest value of hue angle of chilli obtained from two-stage temperature was observed. In all cases, hue angle was commercially acceptable in the range of 35-45 degrees on the basis of chilli powder, which is a reddish-orange hue color (Osuna-Garcia and Wall, 1998).

Since it is difficult to interpret three values separately, all criteria used for the evaluation of dried chilli quality were in terms of its color attribute. It was observed that the mechanical drying method using a one-temperature regime provided a dark-red color in dried chilli, particularly at 70°C. These results agreed with the findings of Vega-Gálvez *et al.* (2008), Turhan *et al.* (1997) and Lee *et al.* (1991) who have

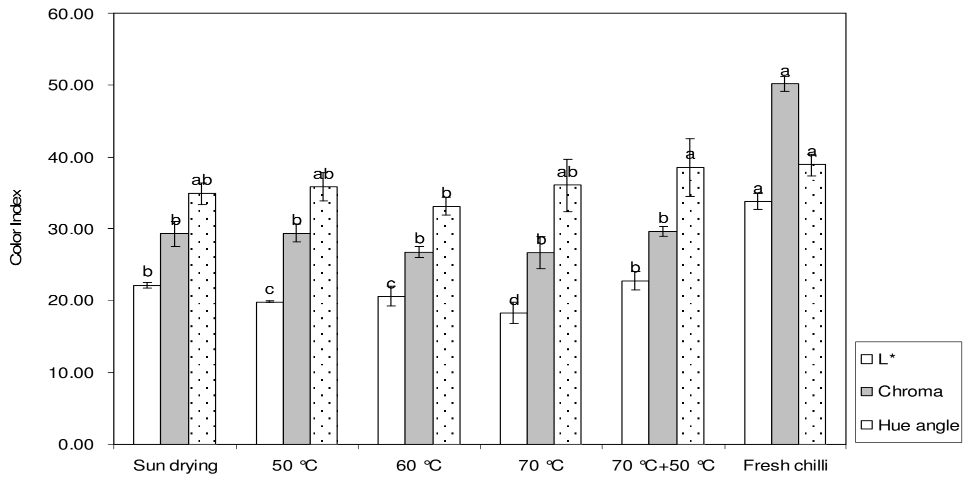


Figure 2. Color attributes of chilli using different drying air temperatures compared to sun drying

suggested that using high temperatures for drying air results in a dark-brown color due to non-enzymatic browning reaction. On the other hand, using a two-stage temperature regime resulted in having a more pure light-red color for dried chilli. Normally fruit and vegetable drying occurs in the falling rate period, thereby it can be treated as a purely diffusion-controlled mass transport phenomenon (Wang and Brennan, 1995; Simal *et al*., 1999). As a result, an internal factor plays an important role for moisture removal rather than external factors. According to the experiments, two-stage temperature drying was initiated by a higher temperature followed by the low temperature, thus a product tempering period was obtained. During this period, the product temperature had an adequate enough high temperature for moisture diffusion from the center to the surface of product. Thus, moisture removal of chilli during drying can still be obtained during the second stage of drying without excessive heating, particularly on the product surface, and this prevents a dark brown color forming. Therefore, at a lower drying air temperature, a better quality of chilli can be observed.

Nutrition compounds of dried chilli obtained from different drying air temperatures were also monitored and compared with the sun drying method. Table 1 shows that the reducing sugar levels of the chilli were between 4.99-5.26 mg/g dried chilli and all drying methods were not significantly different but were significantly lower than fresh chilli. Even though different drying air temperatures did not significantly affect reducing sugar, the decrease in reducing sugar resulted in the forming of browning compounds due to the non-enzymatic browning reaction between reducing sugar and amino acid (Lee *at al*, 1991). This result is compatible with the decrease in lightness, chroma and hue angle compared to fresh-blanched chilli (L^{*}= 33.8 ± 1.1, C*=50.2 ± 1.02, H*=38.9 ± 1.5). The total phenolic compounds of dried chilli obtained from different drying air temperatures did not significantly differ with sun drying (P>0.05), except when a drying air temperature of 60^{o}C was used (Table 1). The explanation could be that a long drying period using a low drying air temperature (50^{o}C and sun drying) resulted in an increase with the loss of phenolic compounds due to oxidation induced by the presence of oxygen and light (von Elbe and Schwartz, 1996). This finding agrees with Erbay and Icier (2009) who using drying air temperatures of

Table 1. Nutritional values of chilli at different drying air temperatures

Drying method	Reducing sugar (mg/g dried chilli)	Ascorbic acid (mg/100 g dried chilli)	Total phenolic compounds (mg/100 g dried chilli)
Sun drying	5.26±0.40b	35.76±2.11c	255.15±18.70c
50°C	4.99±0.88b	49.31±1.03b	253.84±28.52c
60°C	5.18±0.55b	45.20±4.51b	312.20±11.00b
70°C	5.26±0.38b	38.02±3.95c	266.84±11.66c
70°C+50°C	5.13±0.13b	39.02±1.72c	263.13±6.22c
Fresh chilli	6.51±0.67a	344.32±48.1a	468.29±10.9a

between 40-60°C for olive leaves drying. On the other hand, drying air temperatures higher than 60°C (70°C and 70°C-50°C) provided a lower value of phenolic compounds due to thermal degradation (von Elbe and Schwartz, 1996). The optimum drying air temperature of 60°C for phenolic compounds retention was similar to Katsube *et al*. (2009) who used the temperatures of 40-110°C for mulberry leaves drying. In all treatments, decreases in the total phenolic compounds were observed compared with the fresh form (468± 10.9 mg/ 100 g dried chilli).

The same results were found for ascorbic acid in dried chilli. As drying air temperatures using a lab-scaled dryer increased, decreases in ascorbic acid were noted (Table 1). The expected result agrees well with those of Vega-Gálvez *et al.* (2008) and Di Scala and Crapiste (2007). Ascorbic acid was degraded by higher temperatures and the degradation product (L-dehydroascorbic acid, DHAA) could participate in Strecker degradation with amino acid, producing a browning pigment (BeMiller and Whistler, 1996). Not only does the high temperature of drying air affect the loss of ascorbic acid, but a long period of drying time can also introduce a significant loss of ascorbic acid. From the experiments the sun drying method took 3-5 days and a two-stage drying method took 16-17 hours compared to the one-temperature regime. The loss of ascorbic acid using the sun drying method was due to oxidation as the dried chilli was exposed directly to light and sun (Gregory, 1996).

Since the color of dried chilli is the main attribute for consumer acceptance, the lightness, chroma and hue angle can be used as major criteria for process optimisation (Vega-Gálvez *et al.*, 2008, Doymaz and Pala, 2002; Sigge *et al.*, 1999; Onsuna-Garcia and Wall, 1998). It was found that the two-stage temperature regime, using a temperature of 70°C for 4 hours and followed by 50°C until reaching the required moisture content, provided the highest values of lightness, chroma and hue angle. However, there were low values in terms of ascorbic acid and phenolic compounds. Meanwhile, a drying air temperature at 70°C provided the lowest value of lightness and chroma, and low values of ascorbic acid and total phenolic compounds. Therefore, these two drying methods were selected to study further their potential for color and nutrition stability in chilli using a mechanical dryer in conjunction with the use of chemical pretreatments.

Using chemical substances for color and nutrients stability of dried chilli

The fresh-blanched chilli were treated with chemical substances, which

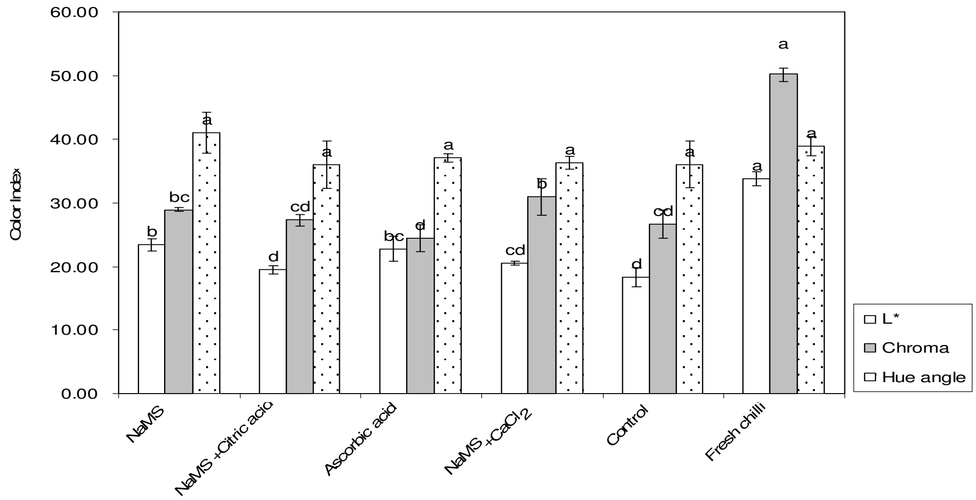


Figure 3. Color attributes of chilli treated with chemical substances using 70°C

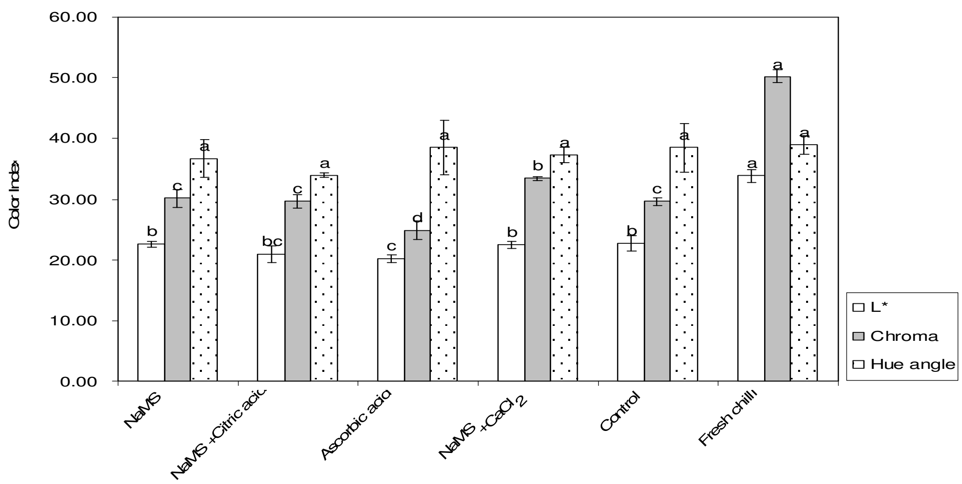


Figure 4. Color attributes of chilli treated with chemical substances using two-stage temperature

were 0.3 % NaMS, 1% ascorbic acid , 0.3 % NaMS combined with 1 % citric acid and 0.3 % NaMS combined with 1 % $CaCl_2$. The moisture content of dried chilli, using drying air temperature at 70°C and using a two-stage temperature regime was between 9.1-10.3% db and 8.9-9.7% db respectively. These values were not significantly different ($P<0.05$). The water activities of dried chilli obtained from these two drying methods pretreated with chemical substances were between 0.39-0.43. Figure 3 shows that using chemical pretreatments, in particular NaMS, improves lightness of dried chilli at drying air temperature 70°C, but the lightness of dried chilli using two-stage temperature was similar to untreated chilli (Figure 4). This suggests that NaMS inhibits browning reaction by binding with the carbonyl group of reducing sugars and other compounds to retard the browning process (Lindsay, 1996). Thus, the browning pigment can be minimized, resulting in a bright color of dried chilli. This result agrees with the findings of Sigge *et al*. (2001) and Simal *et al*., (2005). On the other hand,

Table 2. Nutritional values of chilli soaking in chemical solutions at 70°C

Chemical pretreatments	Reducing sugar (mg/g dried chilli)	Ascorbic acid (mg/100 g dried chilli)	Total phenolic compounds (mg/100 g dried chilli)
NaMS	4.83±0.13c	44.26±1.48c	280.65±3.19c
NaMS + Citric acid	4.79±0.03c	48.28±1.16c	271.34±4.80c
Ascorbic acid	4.84±0.11c	72.25±13.69b	312.93±20.77b
NaMS + $CaCl_2$	4.68±0.19c	42.01±2.04c	283.49±13.74c
Control	5.26±0.38b	38.02±3.95c	266.84±11.66c
Fresh chilli	6.51±0.67a	344.32±48.1a	468.29±10.9a

Table 3. Nutritional values of chilli soaking in chemical solutions at two-stage temperature

Chemical pretreatments	Reducing sugar (mg/g dried chilli)	Ascorbic acid (mg/100 g dried chilli)	Total phenolic compounds (mg/100 g dried chilli)
NaMS	4.91±0.14b	43.59±0.54cd	252.79±4.92c
NaMS+Citric acid	4.45±0.23cd	44.99±0.76c	269.85±6.61c
Ascorbic acid	4.91±0.11b	68.61±6.74b	299.00±7.88b
NaMS +$CaCl_2$	4.52±0.07c	45.80±2.78c	316.61±30.66b
Control	4.11±0.22d	39.02±1.72d	263.13±6.22c
Fresh chilli	6.51±0.67a	344.32±48.1a	468.29±10.9a

using chemical pretreatments with two-stage temperatures was found to produce similar value of lightness compared with the non-pretreated chilli (Figure 4). This was probably due to all chemical substances being degraded by thermal degradation due to the long period of two-stage temperature regime. Therefore, using a lower temperature in the second stage of drying could be enough to retard browning color occurring.

From Figure 3 and 4, the highest value of the Chroma of dried chilli using NaMS combined with $CaCl_2$ was observed at both 70°C and a two-stage temperature regime. As chroma presents the purity of color, using NaMS combined $CaCl_2$ preserved a pure red color, in which carotenoid pigments could be retained. Adding of $CaCl_2$ was found to improve the red color stability, as $CaCl_2$ may react with water molecules resulting in increased water mobility and reduced drying time. Thus, thermal degradation and oxidation of carotenoid can be minimized along with using of NaMS as an inhibitor of browning reaction. This is compatible with the experiment when chilli soaked in NaMS with $CaCl_2$, reduced the drying time from 8.7 to 7.5 hours and from 16.4 to 15 hours for 70°C and a two-stage temperature regime, respectively. These results agree with Davoodi *et al.* (2007) who suggested that calcium may be acting in some manner to block the amino groups before entering into the enzymatic browning reaction. However, it was found that the chemical pretreatments did not significantly affect hue angle when both 70°C and a two-stage temperature regime were used compared to untreated and fresh chilli. The hue angles of chilli using 70^{o}C and a two-stage temperature regime with chemical pretreatments were between 33-42 degrees, which is a reddish-orange hue. Using chemical pretreatments before drying provids the same reddish-orange color of chilli, but different saturation and lightness due to different degrees of browning reaction and oxidation.

Reducing sugar content of dried chilli obtained from different chemical pretreatments was similar (P<0.05) (Table 2) using a drying air temperature of 70^{o}C, but reducing sugar content were significantly decreased compared with the control (P>0.05). Meanwhile, using chemical substances with the two-stage drying temperature method significantly (P>0.05) improve the amount of reducing sugar of dried chilli compared to the non-pretreatment method (Table 3). However, the reducing sugar of dried chilli decreased compared to fresh chilli (6.5 mg/g dried chilli) in all cases. It is suggested that the degradation of the reducing sugar causes the browning pigment to develop due to a Maillard reaction, and therefore a decrease in lightness and chroma was observed.

The total phenolic compounds of dried chilli obtained from 70^{o}C and a two-stage temperature regime were similar to the control (P<0.05), with the exception of using ascorbic acid and NaMS with $CaCl_2$ (Tables 2 and 3). Most notably, the amount of total phenolic compounds was higher than the sun drying method (255 mg/ 100 g dried chilli) and tray drying with non-pretreatment method, while the values decreased compared to freshly-blanched chilli (468 mg/100 g dried chilli). It was observed that using chemical pretreatments could not preserve total phenolic compounds, in spite of blanching that was conducted in order to inhibit enzymatic browning reaction. It can be suggested that the other reactions also play a role for total phenolic degradation, such as thermal degradation or oxidation. Thus, browning pigment possibly develops as a product of these reactions induced by drying air at a high temperature. This finding agrees with Erbay and Icier (2009) and Katsube *et al*. (2009).

As shown in Tables 2 and 3, using a pretreatment method before drying could not prevent the degradation of ascorbic acid both at 70^{o}C and a two-stage temperature regime, with the exception of soaking in ascorbic acid solution which was significantly higher than other chemical pretreatments and control. Generally, ascorbic acid is used for food ingredients as a reducing and antioxidation agent. This contradicted with these results, as the soaking of chilli in this solution was found to lead to a darker color, even though the amount of ascorbic acid was increased after the drying process. This can be explained in that ascorbic acid was oxidized by the high temperature of drying air leading to DHAA and a wide variety of carbonyl and other unsaturated compounds being formed (Gregory, 1996). The breakdown products then participated in Strecker degradation with amino acids and further polymerized to form melanoidins or nonnitrogenous caramel-like pigments (Gregory, 1996). This result was similar to those Arroyo-LÓpez *et al*. (2008), who observed browning color occurring during storage of cracked table olives when ascorbic acid was used between 0.75- 1.5% (w/v). Therefore, using ascorbic acid does not improve the color stability of dried chilli, but rather induces the development of browning for both 70^{o}C and the two-stage temperature. As discussed above, the mechanism of browning pigment developed during chilli drying involves different reactions. It could be suggested that not only does the Maillard reaction cause browning pigment, but also other reactions such as the oxidation of ascorbic acid and phenolic compounds.

Conclusions

A lab-scale tray dryer using a one-temperature regime (50°, 60° and 70°C) provided a darker brown color for dried chilli and low values of lightness (L*), chroma (C*) and hue angle (H*) than those when a two-stage temperature process was used. Reducing sugar, total phenolic compounds and ascorbic acid decreased compared to fresh chilli when using both mechanical and conventional methods. It could be suggested that not only does the drying air temperature affect nutrient stability, but also the drying time. It was found that using NaMS at a drying air temperature of 70°C provided more bright-red color as sulfite inhibits nonenzymatic browning reaction. In addition, soaking in NaMS combined with $CaCl_2$ produced the highest color stability. Reducing sugar and total phenolic compounds could not be preserved by soaking in chemical solutions. However, an increase in ascorbic acid was found in dried chilli treated with ascorbic acid solution for the two drying methods, but a dark-brown color was observed. In order to obtain color stability of dried chilli, it can be suggested that NaMS combined with $CaCl_2$ can be used for pretreatment of chilli before drying at two-stage temperatures of 70°C and 50°C.

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