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EFFECTS OF PRETREATMENTS AND DRYING TEMPERATURES ON DRYING CHARACTERISTICS, ANTIOXIDANT PROPERTIES AND COLOR OF GINGER SLICE

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Abstract

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To reduce the adverse effects of hot air drying, ginger slices were pretreated prior to drying. The effects of 2 pretreatment methods (blanching versus dipping in 0.1% ascorbic acid solution) and drying temperatures (60, 70 and 80 °C) on the drying characteristics and the qualities of the dried ginger slices in terms of total phenolic content (TPC), antioxidant activities (DPPH and ABTS methods) and color were investigated. It was noted that the moisture content for both un-pretreated and pretreated samples decreased more rapidly when drying was performed at higher drying temperatures. However, the drying time of un-pretreated and pretreated samples was not significantly different. The TPC and antioxidant activities of the ginger slices increased markedly after drying. The increase in these values was higher for pretreated samples. The dried ascorbic acid solution dipped sample exhibited the highest values of TPC and antioxidant activity. Moreover, the total color difference of the ascorbic acid solution dipped ginger was slightly lower than the total color difference of the un-pretreated ginger. However, the tested drying temperatures, ranging from 60 to 80 °C, did not affect the final TPC, antioxidant activities, and color of the ginger samples.

Keywords: antioxidant activity, ascorbic acid, blanching, color, drying, ginger, phenolic content

INTRODUCTION

Ginger rhizome (*Zingiber officinale* Roscoe.) has been used not only as a spice and a condiment in food and beverage but also used for its medicinal properties. It has been used for the treatment of migraine headaches, muscular aches, pains, sore throats, common cold, flu-like symptoms, indigestion and even painful menstrual periods (Dugasani *et al.*, 2010; El-Ghorab *et al.*, 2010). Moreover, ginger contains phenolic compounds such as gingerols, zingerone and shogaols, which possess antioxidant, anti-inflammatory and anticancer properties (Stoilova *et al.*, 2007; Chen *et al.*, 2008; Dugasani *et al.*, 2010; Wu *et al.*, 2010). Kaur and Kapoor (2002) determined the total phenolic content (TPC) of 36 vegetables in Asia including ginger. These vegetables were classified into three groups according to their TPC: high (higher than 200 mg catechol/100 g), medium (100–200 mg catechol/100 g) and low (lower than 100 mg catechol/100 g). Ginger was found to be in the group of high TPC. The TPC in ginger was higher than that of turmeric, palak, green chillies, potato, garlic, cabbage, cauliflower and peas. The antioxidant activity of ginger, determined by the β-carotene bleaching method, was greater than 70%, placing it in the group of high antioxidant activity. Foods containing phenolic compounds with anti-oxidation potential can protect against a variety of disease risks, particularly cancer and cardiovascular diseases (Kaur and Kapoor, 2002).

Ginger powder is one of the most popular processed gingers; it can be consumed as a flavored tea and also used as an ingredient in cosmetics. Drying, an important step in the production of ginger powder, can often affect product quality, especially the quantity of antioxidants. It has been reported that TPC and antioxidant activity of ginger increased after drying (Puengphian and Sirichote, 2008). This is due to the conversion of 6-gingerol, which is the most abundant component in the fresh ginger rhizome, to 6-shogaol during drying (Balladin *et al*., 1996; Ali *et al*., 2008; Wu *et al*., 2010). Dugasani *et al*. (2010) reported that 6-shogaol has exhibited more potent antioxidant properties than gingerols; the scavenging potential was in the order of 6-shogaol > 10-gingerol > 8-gingerol > 6-gingerol. Phoungchandang *et al*. (2009) investigated the effect of drying temperatures on the retention of 6-gingerol. It was found that drying at higher temperatures resulted in lower 6-gingerol content. Chumroenphat *et al*. (2011) reported that the TPC and the antioxidant activity of ginger rhizome were higher when drying was performed at higher drying temperatures. However, the browning of ginger was greater at higher drying temperatures (Phoungchandang *et al*., 2009).

Pretreatments with chemicals or blanching prior to drying can improve the quality of the final product by inhibiting various undesirable enzymatic reactions (Nilnakara *et al*., 2009). Phoungchandang *et al*. (2009) reported that the total color difference of the dried ginger obtained from soaking in citric acid solution was lower than that of the un-pretreated sample, indicating less browning of pretreated sample. Pretreatments also have a significant effect on the phenolic content in fruits and vegetables. Rocha and Morais (2005) reported that the TPC in apple cubes dipped in ascorbic acid was higher than that of the un-pretreated sample. Ascorbic acid can inactivate browning enzymes such as polyphenoloxidase (PPO), which is a catalyst of the hydroxylation of monophenols to o-diphenols and the oxidation of o-diphenols to o-quinones (Gil *et al*., 1998; Piližota and Šubaric', 1998). Ascorbic acid can also reduce o-quinones back to phenolic compounds before they form brown pigments (Gil *et al*., 1998).

In the case of blanching, phenolic compounds may be lost to the blanching water. Nilnakara *et al*. (2009) found that the TPC in cabbage decreased after 2 min of blanching in hot water. The decrease in TPC during blanching was also found in various fruits and vegetables such as carrot peel (Chantaro *et al*., 2008) and lime residue (Kuljarachanan *et al*., 2009). However, blanching can also inhibit PPO (Piližota and Šubaric', 1998; Trirattanapikul and Phoungchandang, 2012), resulting in preservation of phenolic compounds during subsequent drying. Nilnakara *et al*. (2009) found that dried blanched cabbage could retain TPC slightly better than dried unblanched cabbage. Moreover, the loss of total antioxidant activity in dried blanched cabbage was lower than that of dried unblanched cabbage. Presently there is little information about the effects of pretreatment and drying on the quality of ginger slices, especially in terms of total phenolic content and antioxidant activity.

The purpose of this work was to study the effects of 2 pretreatments, blanching and dipping in ascorbic acid solution, and drying temperatures on the drying characteristics and the qualities of the dried ginger slices in terms of TPC, antioxidant activities (as assessed by DPPH and ABTS methods) and color.

MATERIAL AND METHODS

Chemicals

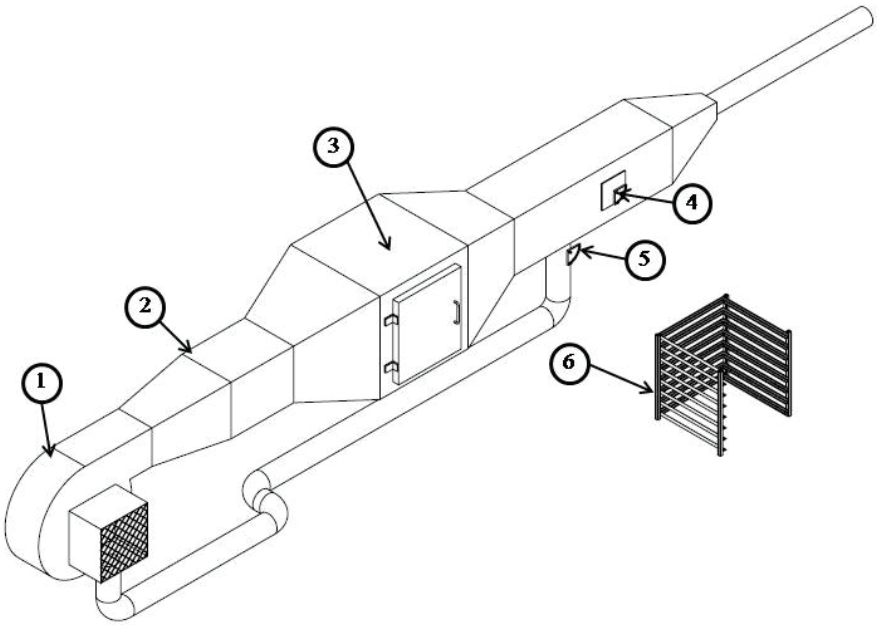
2,2-diphenyl-1-picrylhydrazyl radicals (DPPH), 2,2'-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), Folin-Ciocalteu's phenol reagent, gallic acid were obtained from Sigma–Aldrich (Steinheim, Germany). Potassium persulphate and sodium carbonate were purchased from Ajax Finechem (NSW, Australia). Methanol (HPLC grade) was obtained from Lab-Scan Analytical Sciences (Bangkok, Thailand).

Experimental Set-up

A cabinet dryer as illustrated in Fig. 1 was used in this study. It consists of a forward curved blade centrifugal fan, five 2.5 kW electrical heaters, a drying chamber with a dimension of 0.51 × 0.51 × 0.51 m, perforated trays with a size of 0.23 × 0.29 m. Ambient air was heated by the electrical heaters under a proportional-integral-derivative (PID) control. The heated air was delivered to the drying chamber by the forward curved blade centrifugal fan driven by a 2.2 kW motor. Air velocity was fixed at 0.3 m/s by setting rotation speed of the motor using a frequency inverter. The sample trays were placed in parallel direction with the air flow.

Sample Preparation

Ginger rhizomes at a mature stage of 10–12 months old were purchased from a wholesale market in Pathum Thani, Thailand. Their moisture content varied from 9 to 10 kg/kg dry matter. The ginger rhizomes were kept in a cold storage chamber maintained at a temperature of 4 °C until use. Before each experiment, the rhizomes were allowed to reach ambient air temperature. The ginger rhizomes were manually peeled and sliced into 2 mm thickness with a stainless steel knife. To inhibit enzymatic browning reaction, the ginger slices were pretreated by 2 methods. They were either blanched in hot water at 95 ± 1 °C for 2 min or dipped in 0.1% (w/v) ascorbic acid solution for 2 min prior to drying.



1: *Schematic diagram of a cabinet dryer: 1 Blower, 2 Heaters, 3 Drying chamber, 4 & 5 Butterfly valves and 6 Tray rack*

Drying Procedure

The ginger slices were placed on five perforated trays; each tray contained 80 g of ginger slices. The sample trays were then put into the drying chamber. The prepared ginger slices were dried at air temperatures of 60, 70 and 80 °C and at a superficial air velocity of 0.3 m/s. The samples were dried to a final moisture content of approximately 0.05 kg/kg dry matter. Weight loss of samples was continuously recorded by a load cell connected to a weight indicator (A&D, AD4329, Tokyo, Japan) with an accuracy of ± 0.5 g. The moisture content of ginger slices was determined by the vacuum oven method 934.06 (AOAC, 1995). The dried ginger slices were kept in a zipper bag and then packed in a sealed aluminum foil bag. All sample bags were maintained in a desiccator for further analysis. All drying experiments were done in duplicate.

Sample Extraction

The un-dried ginger slices for both un-pretreated and pretreated samples were chopped into small pieces before extraction. The dried ginger samples were ground for 30 s with a grinder and passed through a 0.25 mm sieve to obtain uniform size powder. The chopped ginger or dried ginger powder was placed in a 250 mL flask and mixed with methanol at a concentration of 3 mg dry matter/mL of solvent. Then it was continuously shaken for 24 h at 30 °C using an orbital shaker. The extracts were filtered through a No. 1 Whatman filter paper. The filtrate was further analyzed for total phenolic content and antioxidant activity. Each treatment was duplicated.

Determination of Total Phenolic Content (TPC)

Total phenolic content (TPC) in the ginger extracts was determined using the Folin-Ciocalteu reagents assay according to the method of Chan *et al.* (2008), with the following modifications. The ginger extract (0.3 mL) was placed in a centrifuge tube. It was mixed with 1.5 mL of Folin-ciocalteu reagents, diluted 10 times, and shaken for 1 min. The mixture was then added with 1.2 mL of 7.5% (w/v) sodium carbonate solution, and shaken for 30 s. The mixture was kept in the dark, at room temperature, for 60 min. The absorbance was measured at 765 nm using a spectrophotometer. The results are expressed as gallic acid equivalents in milligram per gram of dry sample (mg GAE/g dry matter).

Determination of Antioxidant Activities

2,2-diphenyl-1-picrylhydrazyl (DPPH) Radical Scavenging Activity

DPPH radical scavenging activity of ginger extracts was determined according to the method of Chen *et al.* (2008), with the following modifications. Two milliliters of DPPH methanolic solution (3.9 mg/100 mL methanol) were mixed with 0.5 mL of ginger extract in a centrifuge tube. The mixture was shaken for 30 s and then kept in the dark, at room temperature, for 30 min. The absorbance was measured at 517 nm using a spectrophotometer. The results are expressed as a percentage of DPPH radical scavenging activity as follows:

$$\text{Scavenging activity (\%)} = \left(\frac{\text{Abs}_{\text{blank}} - \text{Abs}_{\text{sample}}}{\text{Abs}_{\text{blank}}}\right) \times 100, \quad (1)$$

The blank was prepared by replacing the ginger extract with methanol (0.5 mL).

2,2'-Azinobis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) Assay

The ABTS assay was determined according to the method of Re *et al.* (1999), with the following modifications. ABTS solution (7 mM) was mixed with 2.45 mM potassium persulfate solution at a ratio of 1:1. The mixture was kept in the dark, at room temperature, for 16 h. The ABTS radical cation ($ABTS^{\bullet+}$) solution (2 mL) was diluted with 96 mL of methanol to obtain an absorbance value of 0.7±0.05 at 734 nm. Ginger extract (0.1 mL) was mixed with 3.9 mL of the diluted $ABTS^{\bullet+}$ solution and shaken for 30 s. The solution was kept in the dark, at room temperature, for 7 min. The absorbance was measured at 734 nm using a spectrophotometer. The results are expressed as a percentage of ABTS radical scavenging activity as follows:

$$\text{Scavenging activity (\%)} = \left(\frac{\text{Abs}_{\text{blank}} - \text{Abs}_{\text{sample}}}{\text{Abs}_{\text{blank}}} \right) \times 100, \quad (2)$$

The blank was prepared by replacing the ginger extract with methanol (0.1 mL).

Color Measurement

The color of un-dried ginger slices and dried ginger powder was measured using a colorimeter (ColorFlex, HunterLab, USA), which gave L-, a-, and b-values. L-value represents lightness, a-value represents redness and b-value represents yellowness. The total color difference of dried ginger powder was calculated by the following equation:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}, \quad (3)$$

where $\Delta L = L_{ud} - L_d$, $\Delta a = a_{ud} - a_d$, $\Delta b = b_{ud} - b_d$, and L_{ud}, a_{ud}, and b_{ud} are the color coordinates of the un-dried ginger slices and L_d, a_d, and b_d are the color coordinates of the dried ginger powder. Before each color measurement, the colorimeter was calibrated with standard white and black plates. Each experiment was done in duplicate.

Statistical Analysis

The data were analyzed using the analysis of variance (ANOVA). Differences between mean values were established using Tukey's multiple range test. Mean values were considered at 95% confidence level.

RESULTS AND DISCUSSION

Drying Characteristics of Un-pretreated and Pretreated Ginger Slices

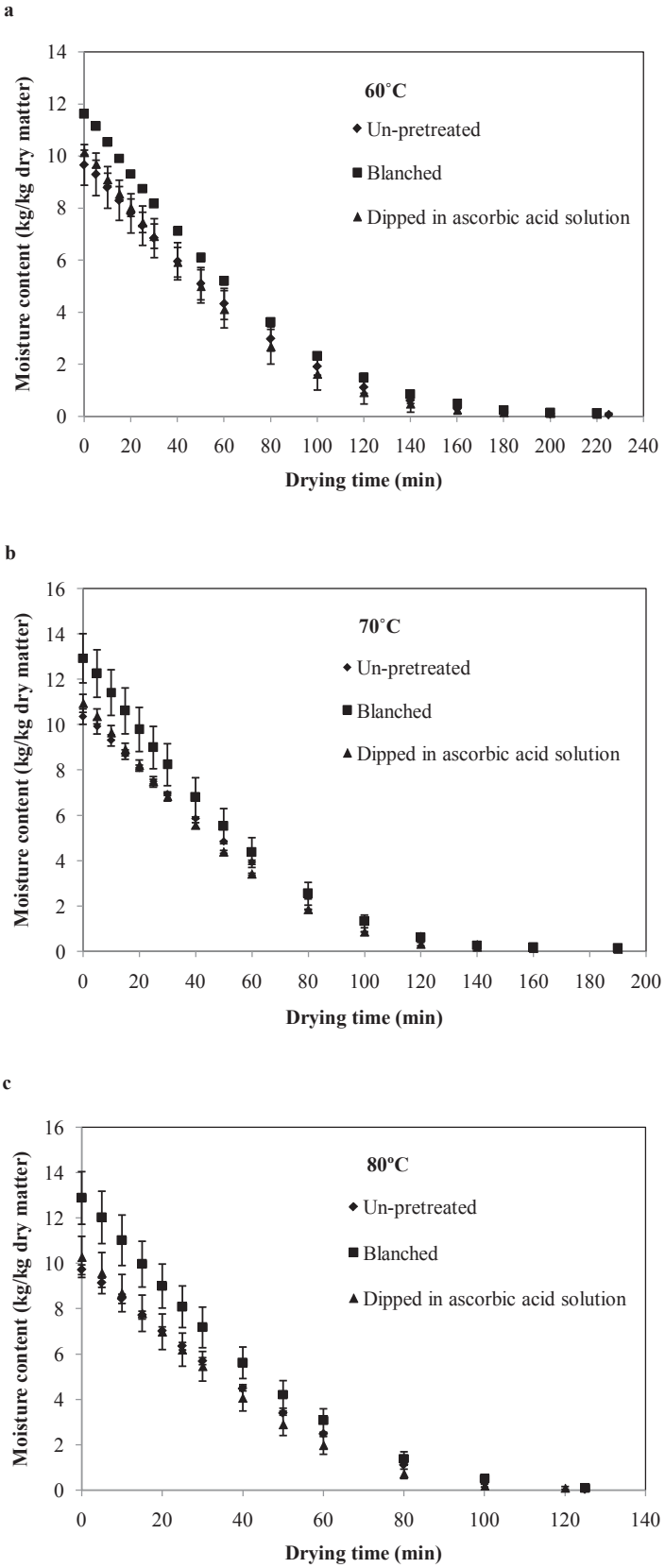
Fig. 2 shows the drying curves of pretreated (blanched and dipped in ascorbic acid solution) and un-pretreated ginger slices, which were dried at 60, 70 and 80 °C. The initial moisture content of un-pretreated ginger was approximately 10 kg/kg dry matter. The blanched ginger had higher initial moisture content compared to the un-pretreated ginger, approximately 12–13 kg/kg dry matter. This is probably due to structural softening during blanching or cooking (Chantaro *et al.*, 2008; Nilnakara *et al.*, 2009; Doymaz, 2013), which could enhance moisture absorption. However, the initial moisture content of ginger slices dipped in ascorbic acid solution was slightly higher than that of un-pretreated ginger, approximately 10–11 kg/kg dry matter. This is because dipping ginger slices in the ascorbic acid solution at ambient temperature for only 2 min could soften the structure of ginger to a lesser degree compared to blanching. Hence, the increase in its moisture content was slight.

It is observed from Fig. 2 that the moisture content decreased exponentially with increasing drying time for both un-pretreated and pretreated ginger slices, illustrating the falling rate period drying as shown in Fig. 3. It is also seen from Fig. 3 that the drying rates of pretreated ginger were higher than those of un-pretreated ginger. This is probably due to softer and looser structure of the pretreated samples, which could facilitate the removal of moisture during drying (Chantaro *et al.*, 2008; Nilnakara *et al.*, 2009; Doymaz, 2013). Moreover, drying temperature also affected the drying rates. The drying rates for both un-pretreated and pretreated ginger slices were higher when drying was performed at higher drying temperatures as can be seen in Fig. 3, due to higher moisture diffusivities.

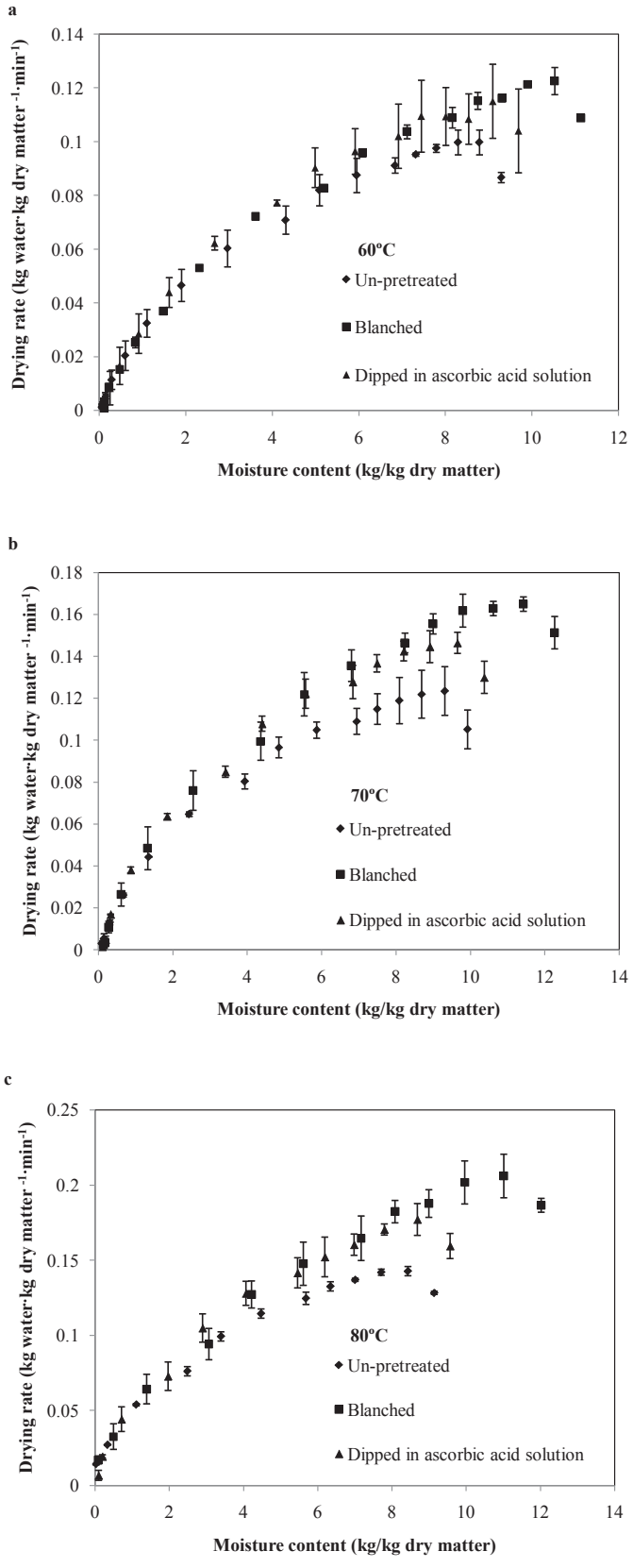
Tab. I shows the time required for reducing the moisture content of pretreated and un-pretreated ginger slices, which were dried at 60, 70 and 80 °C, to about 0.05 kg/kg dry matter. It was found that the required drying time of pretreated ginger was not shorter than that of un-pretreated ginger although the drying rates of the pretreated samples were higher than those of the un-pretreated sample. This is because the initial moisture content of the pretreated sample was higher than that of the un-pretreated sample. However, the drying time for both un-pretreated and pretreated samples was shorter at higher drying temperatures as shown in Tab. I.

Total Phenolic Content

The TPC in un-dried and dried ginger slices for both un-pretreated and pretreated samples is given in Tab. II. The TPC in fresh (un-dried and un-pretreated) ginger was 15.41 mg GAE/g dry matter. Chen *et al.* (2008) determined the TPC in the methanol extracts of different ginger species in Taiwan; their TPC values ranged from 15.3 to 36.5 mg GAE/g dry matter. The different TPC values they reported might be due to different initial TPC in the species or cultivars or even geographic origin of the ginger they used. The maturity of the plant also affects the TPC in ginger rhizome.



2: *Drying curves of un-pretreated and pretreated ginger slices dried at different drying temperatures: (a) 60, (b) 70 and (c) 80 °C*



3: *Drying rate curves of un-pretreated and pretreated ginger slices dried at different drying temperatures: (a) 60, (b) 70 and (c) 80 °C*

Chumroenphat *et al*. (2011) reported that the ginger rhizome at 12 months after planting had higher TPC than that at 9 months after planting.

The blanched ginger had lower TPC than the fresh ginger. There was a 25% loss of TPC after 2 min of blanching as can be seen in Tab. II. This might be due to the loss of TPC to the blanching water. The reduction of TPC during blanching was also found in cabbage (Amin and Lee, 2005), carrot peel (Chantaro *et al*., 2008), cabbage outer leaf (Nilnakara *et al*., 2009) and lime residue (Kuljarachanan *et al*., 2009). However, the TPC in some vegetables such as Ewuro-odo (*Structium sparejanophora*), African basil (*Ocimum gratissimum*) and African eggplant (*Solanum macrocarpon*) increased after blanching (Oboh, 2005). This could be attributed to the breakdown of tannins into simple phenols during blanching. However, tannins are not major compounds in ginger (Nwinuka *et al*., 2005). In the case of ginger slices dipped in ascorbic acid solution, it was found that TPC was similar to that of fresh ginger. This result is in agreement with the finding of Rababah *et al*. (2005), who found an insignificant difference in TPC values between sample pretreated by dipping in 0.1% (w/v) ascorbic acid solution (for 2 min) and the un-pretreated sample. In contrast, Rocha and Morais (2005) found an increase in TPC in apple cubes after 5 min of dipping in 0.75% (w/v) ascorbic acid solution. This could be attributed to the higher concentration of ascorbic acid solution and longer dipping time.

It is clear from Tab. II that TPC increased markedly after drying for both un-pretreated and pretreated ginger slices. This result is in agreement with that obtained by Puengphian and Sirichote (2008). An increase in TPC after drying has been attributed to the liberation of bound phenolic compounds by the breakdown of cellular tissues (Haard and Chism,

I: *Drying time of pretreated and un-pretreated ginger slices dried at the temperatures of 60, 70 and 80 °C*

Sample	Drying temperature (°C)	Drying time (min)
Un-pretreated	60	225
	70	190
	80	125
Blanched	60	220
	70	190
	80	125
Dipped in ascorbic acid solution	60	220
	70	190
	80	120

II: *Total phenolic content DPPH and ABTS radical scavenging activities of un-dried and dried ginger slices at various conditions*

Sample Condition	Total phenolic content (mg GAE/g dry mater)	DPPH (% scavenging activity)	ABTS (% scavenging activity)
Un-dried			
Un-pretreated	15.41 ± 1.05^{c}	86.67 ± 0.65^{cd}	47.28 ± 1.29^{e}
Blanched	11.60 ± 1.18^{d}	81.14 ± 0.43^{e}	42.39 ± 2.02^{f}
Dipped in ascorbic acid solution	15.39 ± 1.86^{c}	84.77 ± 2.38^{d}	45.28 ± 2.99^{ef}
Dried			
Un-pretreated			
60 °C	18.71 ± 0.12^{b}	87.51 ± 0.52^{bc}	53.93 ± 0.56^{d}
70 °C	18.62 ± 0.04^{b}	87.37 ± 1.16^{bc}	54.37 ± 3.36^{d}
80 °C	19.0 ± 0.17^{b}	87.33 ± 0.19^{bc}	55.03 ± 0.38^{cd}
Blanched			
60 °C	16.90 ± 0.78^{bc}	87.25 ± 0.23^{bcd}	56.14 ± 1.05^{bcd}
70 °C	17.76 ± 0.05^{b}	87.56 ± 0.50^{bc}	54.84 ± 1.10^{cd}
80 °C	16.90 ± 0.63^{bc}	87.70 ± 0.48^{bc}	55.56 ± 0.53^{bcd}
Dipped in ascorbic acid solution			
60 °C	21.91 ± 0.00^{a}	90.25 ± 0.39^{a}	59.89 ± 0.54^{ab}
70 °C	22.73 ± 0.19^{a}	90.59 ± 0.31^{a}	61.68 ± 9.7^{a}
80 °C	21.30 ± 0.29^{a}	89.38 ± 0.11^{ab}	59.40 ± 1.10^{abc}

Values are means ± SD (n = 2)
Values in the same column with different superscripts mean that the values are significantly different ($p < 0.05$)

1996) and the formation of new compounds such as shogaols and zingerone (Balladin *et al*., 1996; Ali *et al*., 2008; Wu *et al*., 2010). The increase in the TPC after drying was higher for pretreated samples. The TPC in blanched and ascorbic acid solution dipped samples increased by 46% and 43%, respectively while the TPC in the un-pretreated sample increased by only 22% after drying. This is probably because pretreatments can inactivate browning enzymes responsible for the reduction of phenolic compounds (Piližota and Šubaric', 1998). The dried ascorbic acid solution dipped sample exhibited the highest TPC with values ranging of 21.30–22.73 mg GAE/g dry matter.

The tested drying temperatures, ranging from 60 to 80 °C, did not affect the TPC in un-pretreated and pretreated ginger slices. However, drying at higher temperatures would accelerate the formation rate of new compounds. A shorter drying time is required at higher drying temperatures, resulting in the similar values of TPC in samples dried at different temperatures. This result is inconsistent with that of Chumroenphat *et al*. (2011), who reported that the TPC in ginger rhizome increased with increasing drying temperature.

Antioxidant Activities

Tab. II shows DPPH and ABTS radical scavenging activities of un-dried and dried ginger slices for both un-pretreated and pretreated samples. The DPPH and ABTS radical scavenging activities of fresh ginger were 86.7 and 47.3%, respectively, indicating that ginger could inhibit DPPH radicals more efficiently than ABTS radicals. The blanched ginger showed lower DPPH and ABTS inhibition compared to the fresh and the ascorbic acid solution dipped samples. This is probably due to a lower value of TPC in the blanched sample. Chumroenphat *et al*. (2011) found a positive correlation between TPC and DPPH assay of ginger extracts; the samples with higher TPC showed higher antioxidant activity. This indicated that phenolic compounds in ginger contributed to their antioxidant activity.

The antioxidant activities of dried ginger slices for both un-pretreated and pretreated samples were higher than those of the un-dried samples as can be seen in Tab. II. This might be due to the conversion of 6-gingerol to 6-shogaol during drying (Balladin *et al*., 1996; Ali *et al*., 2008; Wu *et al*., 2010). The amount of 6-shogaol in dried ginger was higher than that of the un-dried ginger (Balladin *et al*., 1996; Jolad *et al*., 2005). Dugasani *et al*. (2010) investigated the effect of major non-volatile compounds in ginger, i.e., gingerols and 6-shogaol, on their DPPH radical scavenging potential. They reported that the DPPH radical scavenging potential of ginger was in the order of 6-shogaol > 10-gingerol > 8-gingerol > 6-gingerol. Recently, only 6-gingerol has received much attention in its nutraceutical properties. However, the findings of Dugasani *et al*. (2010) have shown that 6-shogaol is a more potent antioxidant agent than 6-gingerol. As shown in Tab. II, the dried ascorbic acid solution dipped ginger slices exhibited the highest DPPH and ABTS radical scavenging activities with values of approximately 90% and 60%, respectively. Both values had a positive correlation with the TPC. The antioxidant activities of ginger slices dried

III: *Color of un-dried ginger slices and dried ginger powder at various conditions*

Sample Condition	*L* – value	*a* – value	*b* – value	Δ*E*
Non-dried				
Un-pretreated	54.78 ± 0.22^{f}	-1.03 ± 0.80^{cf}	17.40 ± 0.76^{e}	-
Blanched	51.15 ± 0.13^{g}	-0.20 ± 0.02^{e}	15.37 ± 0.55^{f}	-
Dipped in ascorbic acid solution	56.51 ± 0.55^{e}	-1.20 ± 0.01^{f}	17.40 ± 0.21^{e}	-
Dried				
Un-pretreated				
60 °C	64.08 ± 0.49^{bc}	2.65 ± 0.03^{cd}	23.42 ± 0.03^{a}	11.70 ± 0.42^{a}
70 °C	64.69 ± 0.02^{ab}	2.21 ± 0.02^{d}	22.02 ± 0.05^{bc}	11.42 ± 0.76^{ab}
80°C	63.78 ± 0.27^{bc}	2.96 ± 0.04^{bcd}	23.33 ± 0.01^{a}	11.51 ± 0.64^{ab}
Blanched				
60 °C	57.22 ± 0.07^{de}	4.35 ± 0.04^{a}	20.25 ± 0.27^{d}	9.03 ± 0.18^{c}
70 °C	57.48 ± 0.06^{d}	4.17 ± 0.01^{a}	20.11 ± 0.04^{d}	9.03 ± 0.33^{c}
80 °C	57.67 ± 0.08^{d}	3.86 ± 0.00^{ab}	21.43 ± 0.06^{c}	9.78 ± 0.34^{abc}
Dipped in ascorbic acid solution				
60 °C	65.26 ± 0.09^{a}	2.52 ± 0.01^{d}	21.80 ± 0.30^{c}	10.47 ± 0.46^{abc}
70 °C	64.19 ± 0.05^{bc}	2.61 ± 0.04^{cd}	21.82 ± 0.04^{c}	9.64 ± 0.58^{bc}
80 °C	63.63 ± 0.06^{c}	3.50 ± 0.01^{abc}	23.12 ± 0.01^{ab}	10.27 ± 0.53^{abc}

Values are means ± SD (n = 2)
Values in the same column with different superscripts mean that the values are significantly different (< 0.05)

at drying temperatures ranging from 60 to 80 °C were not significantly different.

Color

The color of un-dried ginger slices and dried ginger powder for both un-pretreated and pretreated samples in terms of L-, a- and b-values is presented in Tab. III. The ascorbic acid solution dipped sample was brighter than the fresh sample as manifested by a higher L-value. This is because dipping in ascorbic acid solution inhibits browning enzymes such as PPO (Piližota and Šubaric', 1998). This result is in agreement with the experimental result reported by Rababah *et al.* (2005) who found that the samples (apple, peach and strawberry) dipped in ascorbic acid solution had significantly higher L-value than the un-pretreated samples. Blanching could also inhibit PPO (Piližota and Šubaric', 1998; Trirattanapikul and Phoungchandang, 2012) but the blanched sample became darker with a slight loss of yellowness as manifested by lower L- and b-values. This might be due to the destruction of pigments during blanching (De Corcuera *et al.*, 2004).

The total color difference (ΔE), which can be calculated from equation (3), was found to be lower for pretreated samples as seen in Tab. III. This indicated less browning of pretreated samples during subsequent drying. However, the dried ascorbic acid solution dipped sample was brighter than the dried blanched sample. The total color difference of ginger slices dried at drying temperatures ranging from 60 to 80 °C was not significantly different.

CONCLUSIONS

Drying of ginger slices mostly occurred in the falling rate period. The drying rates of ginger slices were higher when drying was performed at higher drying temperatures. However, the drying time of un-pretreated and pretreated samples was not significantly different. The TPC in un-pretreated and pretreated samples increased markedly after drying. A greater increase in TPC was obtained for pretreated samples due to the inactivation of browning enzymes responsible for the reduction of phenolic compounds. The DPPH and ABTS radical scavenging activities of ginger slices had a positive correlation with TPC. However, the TPC, antioxidant activities, and color of ginger slices dried at drying temperatures ranging from 60 to 80 °C were not significantly different.

SUMMARY

The purpose of this work was to study the effects of 2 pretreatments, blanching and dipping in ascorbic acid solution, and drying temperatures on the drying characteristics and the qualities of the dried ginger slices in terms of TPC, antioxidant activities (as assessed by DPPH and ABTS methods) and color. The DPPH and ABTS radical scavenging activities of the dried samples were higher than those of the un-dried samples, justifying the use of dried ginger for antioxidant properties. Dried ascorbic acid solution dipped ginger exhibited the highest values of TPC and antioxidant activities. Dried blanched ginger powder had the lowest value of total color difference, however, it had lower TPC and antioxidant activities compared to the dried ascorbic acid solution dipped sample, due to the loss of TPC into the hot water during blanching. The tested drying temperatures, ranging from 60 to 80 °C, did not affect the TPC, antioxidant activities, and color of the ginger samples. However, drying at higher drying temperatures required a shorter drying time. To produce ginger powder, pretreatment of ginger slices by dipping in 0.1% ascorbic acid solution prior to drying at a temperature of 80 °C is recommended.

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