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INFLUENCE OF DRYING AND ROASTING TEMPERATURES AND HUMIDITY ON THE CONTENT OF POLYPHENOLS AND FLAVONOIDS, ANTIOXIDANT ACTIVITY, AND QUALITY OF GINGER TEA

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Abstract

Ginger tea is a popular drink in Asian countries and has many health benefits. However, its production process is complicated as it requires the product to retain biologically active compounds and sensory criteria. The purpose of the research was to determine the heat treatment regime in the drying stage, the moisture content after drying, the roasting temperature, and the appropriate product moisture content to preserve the polyphenol content, antioxidant activity, flavonoid content, and quality of ginger tea products. The research results showed that when ginger was dried at 60 % moisture content, then roasted at 140 °C to 8 % product moisture content, good results were achieved in maintaining the polyphenol content (9.85 ± 0.18 mg GAE/g dw), antioxidant activity (27.02 ± 0.17 µmol TE/g dw), flavonoid content (25.51 ± 0.18 mg QE/100 g dw), water activity (0.48 ± 0.01) and the quality of ginger tea. The optimal experimental conditions obtained can be easily applied to the ginger tea production process on a larger scale in the future.

Keywords: antioxidant activity; flavonoid; ginger tea; polyphenols.

ВПЛИВ ТЕМПЕРАТУРИ І ВОЛОГОСТІ СУШІННЯ ТА ОБСМАЖУВАННЯ НА ВМІСТ ПОЛІФЕНОЛІВ І ФЛАВОНОЇДІВ, АНТИОКСИДАНТНУ АКТИВНІСТЬ ТА ЯКІСТЬ ІМБИРНОГО ЧАЮ

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Анотація

Імбирний чай – дуже корисний для здоров’я, популярний, особливо в країнах Азії, напій. Однак процес його виробництва є складним, оскільки продукт повинен зберігати біологічно активні сполуки та смакові якості. Метою дослідження було визначення режиму теплової обробки на стадії сушіння, вмісту вологи після сушіння, температури обсмажування та відповідної вологості продукту для збереження вмісту поліфенолів, антиоксидантної активності, вмісту флавоноїдів та якості виробів з імбирного чаю. Результати досліджень показали, що за умови сушіння імбиру до вологості 60 % з подальшим обсмажуванням за 140 °C (до вологості продукту 8 %), були досягнуті хороші результати щодо збереження вмісту поліфенолів (9.85 ± 0.18 мг GAE/г сирого), антиоксидантної активності (27.02 ± 0.17 мкмоль TE/г сирого), вмісту флавоноїдів (25.51 ± 0.18 мг QE/100 г сирого), активності води (0.48 ± 0.01) та якості імбирного чаю. Отримані оптимальні експериментальні умови можуть бути легко застосовані до процесу виробництва імбирного чаю в більш широких масштабах у майбутньому.

Ключові слова: антиоксидантна активність; флавоноїди; імбирний чай; поліфеноли.

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Introduction

Ginger (*Zingiber officinale* Roscoe) is a plant grown in many tropical and subtropical countries. It is widely used as a spice in many types of beverages and foods [1]. Ginger has several health benefits, allowing it to be widely used in growing markets for functional foods and nutrition in various natural commercial products [2]. Ginger contains polyphenolic compounds (6-gingerol and its derivatives) with high antioxidant activity, minimizing or preventing the generation of free radicals. The antioxidant activity is due to the presence of phenolic compounds, flavonoids, terpenes and some volatile compounds contained in the essential oils of ginger [3]. In Asian countries, ginger tea is a popular beverage similar to traditional tea. Tea is known as the primary source of flavonoids [4]. Many studies have demonstrated that tea and its flavonoids can support cardiovascular health [5]. Drinking tea is associated with the processes of oxidation, anti-inflammation, cancer prevention [6], prevention of heart disease, and other health benefits.

Heat treatment (drying/roasting) is part of the tea production process. However, the content of biologically active compounds in the product after heat treatment is often of little concern. The amount of the different bioactive compounds affects the quality of the product. Gan et al. [8] studied the effects of drying methods on the retention of biologically active compounds in dried products; the rhizomes of ginger (*Zingiber officinale* Roscoe) contain biologically active compounds. Uncontrolled drying conditions can result in the decrease of heat-sensitive biological compounds content, loss of nutrients and sensory value [9]. This same issue applies to the roasting process at high temperatures. However, according to Hossain et al. [10], the drying process makes the tissue samples more brittle, leading to cell wall rupture during grinding, thereby creating homogeneity in the extraction process and releasing more extractable compounds into the solvent. So, reasonable heat treatment will produce a high-quality product.

Based on the above-mentioned studies, a study was conducted on the effect of drying/roasting temperature on the quality of the ginger tea product in order to stabilize the amount of polyphenols, antioxidant activity, and flavonoid content.

Results and their discussion

Effect of drying temperature on ginger tea

Effect of drying temperature on the TPC, TFC, and AC of ginger tea

Drying temperature is one of the very important factors [14]. The temperature of the air used for drying strongly affects the drying rate, as heat is the driving force for moving water from inside the product to the surface and then evaporating it from the surface. Increasing the temperature makes the drying rate of the product faster [15], leading to a shorter drying time. Therefore, too high or too low drying temperature affects the bioactive compounds in ginger tea products. The effects of drying temperature variation on polyphenol content (TPC), antioxidant activity (AC), and flavonoids (TFC) of ginger tea are shown in Table 1.

Table 1

Effect of drying temperatures on the TPC, TFC, and AC of ginger tea

Drying temperature (°C)	TPC (mg GAE/g dw)	TFC (mg QE/100 g dw)	AC (μmol TE/g dw)
50	7.07 ± 0.21^b	21.47 ± 0.28^c	24.73 ± 0.27^b
60	7.84 ± 0.17^b	23.08 ± 0.19^d	25.86 ± 0.18^c
70	6.56 ± 0.25^a	19.90 ± 0.52^b	23.93 ± 0.33^a
80	6.20 ± 0.32^a	19.11 ± 0.37^a	23.68 ± 0.25^a

Different letters in the same column indicate the significant difference of the survey treatments at 95 % confidence level.

The results showed significant TPC, TFC, and AC differences among the samples at different drying temperatures ($p<0.05$). At the drying temperature of 60 °C, TPC, TFC, and AC reached the highest values of 7.84 ± 0.17mg GAE/g dw, 23.08 ± 0.19 mg QE/100 g dw, 25.86±0.18 μmol TE/g dw, respectively. When the drying temperature was increased to 70 °C, the content of these compounds tended to decrease, and they decreased sharply if the drying temperature was further increased to 80 °C. A low drying temperature leads to prolonged drying time, resulting in more oxidation of bioactive compounds by air and an increased loss of bioactive compounds. Lohani and Muthukumarappan [16] indicated that phenolic compounds can be released by heat treatment. Many authors have reported that an increase in drying temperature leads to an increase in the total phenolic extraction [17–18]. However, Gurgenidze et al. [19] mentioned that excessive temperature leads to the degradation of polyphenols and flavonoid content. This result was consistent with the studies by Jamaluddin et al. [20] and Muhamad et al. [21]. Additionally, the AC of ginger tea at different temperature levels was not the same. The material dried at 60 °C had the highest AC (25.86 ± 0.18 µmol TE/g dw), and it started to decrease as the drying temperature increased from 60 °C to 80 °C. Higher drying temperatures lead to the degradation of antioxidant compounds, increased chemical reactions, oxidation of fatty substances in the material, and the formation of new free radicals. At this point, the antioxidant compounds in the material reacted with the newly generated free radicals, reducing the antioxidant capacity of the products [22]. Kishk and Sheshetawy [23] indicated that appropriate heat treatment can enhance the AC of ginger water extract, and 60 °C was the optimal temperature to maximize TPC and AC. Several studies have recommended suitable drying temperatures for ginger ranging from 50 °C to 60 °C [24–25]. Based on the above results, drying at 60 °C was found to be effective in preserving the bioactive compounds.

Effect of drying temperature on the quality of ginger tea

Color parameters and water activity are the important indicators for evaluating product quality, and drying temperature is one of the reasons for food color change [26].

Table 2

Effect of drying temperatures on color and water activity of ginger tea

Drying temperatures (°C)	Color parameters			a_w
	L*	a*	b*	
50	65.60±0.27^c	8.96±0.32^b	19.53±0.29^a	0.51±0.01^a
60	66.98±0.26^d	7.87±0.12^a	19.20±0.24^a	0.52±0.01^{ab}
70	64.69±0.21^b	9.39±0.26^b	20.15±0.13^b	0.52±0.01^{ab}
80	63.74±0.13^a	10.28±0.21^c	20.48±0.18^b	0.53±0.01^b

Different letters in the same column indicate the significant difference of the survey treatments at 95 % confidence level.

Table 2 shows that the L* value of the products showed statistically significant variations at different drying temperatures. Specifically, at a drying temperature of 60 °C, the ginger tea exhibited a higher L* lightness value (66.98 ± 0.26) compared to those of other drying temperatures. Madrau et al. [18] suggested that during low-temperature drying below 60 °C, the presence of oxygen triggers the activity of polyphenol oxidase (PPO) enzymes, promoting the browning reaction. Rocha and Morais [27] reported that as the degree of browning increases, the L* value of the samples decreases. Therefore, drying at a temperature of 50 °C resulted in a lower L* lightness value for ginger tea (65.60 ± 0.27) compared to drying at 60 °C. When increasing the drying temperature to 70 °C and 80 °C, the color of the product also decreased correspondingly, with L* lightness values of 64.69 ± 0.21 and 63.74 ± 0.13; the b* values between the two samples did not have statistically significant differences. While the a* values slightly increased from 7.87 ± 0.12 at 60 °C to 10.28 ± 0.21 at 80 °C. Rahman et al. [28] suggested that drying at excessively high temperatures will strongly impact the color changes of the product. In general, excessively high or low drying temperatures both affect the color of the product. Junqueira et al. [29] observed a decrease in L* and b* values of cape gooseberry fruits during convective drying.

Generally, water activity (a_w) increases as the drying temperature decreases, but it strongly depends on the drying temperature. Drying ginger tea at 50 °C resulted in a lower water activity (a_w=0.51) compared to the a_w of ginger tea when drying at 60 °C, 70 °C, and 80 °C. However, this change of a_w is insignificant. The high drying temperatures caused the initial moisture diffusion process to be fast but later formed a hard layer on the surface, preventing water in the inner layers from moving outward, leading to an increase in a_w and negatively affecting the quality of the product. In this study, drying at 60 °C was chosen as the appropriate drying temperature to keep color and suitable water activity, maintaining the sensory quality of the product.

Effect of moisture content after drying on ginger tea

Effect of moisture content after drying on the TPC, TFC, and AC of ginger tea.

The results in Table 3 show that when the moisture content after drying reached 60 %, the TPC, TFC, and AC of the product were 7.81 ± 0.28 mg GAE/g dw, 23.08 ± 0.19 mg QE/100 g dw, and 25.82 ± 0.22 µmol TE/g dw, respectively, which were better than those at moisture contents of 65 %, 55 %, and 50 %. At a moisture content of 65 %, the moisture content was still relatively high. Hence, the heat was insufficient to convert the phenolics from the insoluble form to the soluble form, which reduced the product's biological activity. According to Latiff et al. [30], most biologically active compounds are very sensitive to temperature, and prolonged drying may lead to the degradation of these compounds. Therefore, decreasing the moisture content after drying to 55 % and 50 %, means the drying time is extended, and the content of bioactive compounds decreases. Generally, the samples dried to a moisture content of 60 % had better TPC, TFC, and AC than the samples dried to 65 %.

Table 3

Effect of moisture contents after drying on the TPC, TFC, and AC of ginger tea

Moisture levels after drying (%)	TPC (mg GAE/g dw)	TFC (mg QE/100 g dw)	AC (μmol TE/g dw)
50	5.43 ± 0.18^a	18.77 ± 0.16^a	24.42 ± 0.19^a
55	5.67 ± 0.21^a	19.04 ± 0.21^a	24.81 ± 0.21^b
60	7.81 ± 0.28^c	23.08 ± 0.19^c	25.82 ± 0.22^d
65	6.23 ± 0.27^b	19.87 ± 0.12^b	25.23 ± 0.16^c

Different letters in the same column indicate the significant difference of the survey treatments at 95 % confidence level.

Effect of moisture content after drying on the quality of ginger tea

Aesthetic color and appropriate water activity (a_w) contribute to improving the quality and sensory properties of the product. Table 4 shows that the moisture content after drying affected the color of the product. The L* value reached the highest value (66.72 ± 0.26) at a moisture content of 60 % and decreased to 65.07 ± 0.21 when the moisture content increased to 65 %. This change can be explained by the fact that high moisture content after drying required a longer time in the heating processes at the same conditions, leading to the Maillard reaction and causing the product color to become darker than at 60% moisture content. When the moisture content decreases from 60 % to 50 %, the L* lightness value also decreases from 66.72 ± 0.26 to 64.32 ± 0.25, as lower moisture content after drying requires a longer drying time, leading to enzymatic and non-enzymatic browning reactions. In addition, the b* color value at 60% moisture content (18.91 ± 0.16) wasn't significantly different from samples at 65 % and 55 %, but was significantly different from the sample at 50 % (20.41 ± 0.14). The results showed that the moisture content of ginger tea after drying, whether higher or lower than 60 %, affected the color of the product.

Table 4

Effect of moisture contents after drying on color and water activity of ginger tea

Moisture levels after drying (%)	Color parameters L*	a*	b*	a_w
50	64.32 ± 0.25^a	9.30 ± 0.12^c	20.41 ± 0.14^b	0.49 ± 0.01^a
55	65.19 ± 0.27^b	8.48 ± 0.13^b	18.87 ± 0.22^a	0.50 ± 0.01^a
60	66.72 ± 0.26^c	7.85 ± 0.18^a	18.91 ± 0.16^a	0.53 ± 0.01^b
65	65.07 ± 0.21^b	8.04 ± 0.14^a	19.02 ± 0.13^a	0.55 ± 0.01^c

Different letters in the same column indicate the significant difference of the survey treatments at 95 % confidence level.

In addition, the results also show that the lower the moisture content after drying is, the lower the a_w is. Specifically, at a moisture content of 65 %, the a_w was 0.55, and when the moisture content was reduced to 60 % and 55 %, the a_w was 0.53 and 0.50, respectively. The a_w at moisture levels of 60 % and 55 % wasn't significantly different at the 5 % level of statistical significance. After continuing to reduce the moisture content to 50 %, the a_w was 0.49. Although the moisture content of 50 % had the lowest a_w, in terms of sensory color, the color was better at 60 % moisture content.

Effect of roasting temperature on ginger tea

Effect of roasting temperature on the TPC, TFC, and AC of ginger tea

Roasting is significant in removing moisture and preserving bioactive substances during preservation, including antioxidant compounds [31]. The results of the TPC, TFC, and AC during roasting at different temperatures are shown in Table 5, indicating that the TPC value increased significantly from 7.35±0.16 mg GAE/g dw at 80 °C to 9.64±0.23 mg GAE/g dw at 140 °C ($p < 0.05$). The TPC value slightly decreased (8.94 ± 0.19 mg GAE/g dw) when the tea was roasted at the highest temperature (160 °C). Phenolic compounds are all capable of antioxidation and are easily oxidized or degraded themselves, especially under heat treatment [32].

Table 5

Effect of roasting temperatures on the TPC, TFC, and AC of ginger tea

Roasting temperatures (°C)	TPC (mg GAE/g dw)	TFC (mg QE/100 g dw)	AC (μmol TE/g dw)
80	7.35±0.16^{a}	19.06±0.15^{a}	24.21±0.21^{a}
100	7.78±0.14^{b}	21.49±0.26^{b}	24.84±0.14^{b}
120	8.52±0.23^{c}	22.72±0.21^{c}	25.37±0.15^{c}
140	9.64±0.23^{e}	24.17±0.25^{e}	26.58±0.24^{e}
160	8.94±0.19^{d}	23.19±0.23^{d}	25.89±0.18^{d}

Different letters in the same column indicate the significant difference of the survey treatments at 95 % confidence level.

Meanwhile, the roasting temperature also affected the ability to release flavonoid compounds, as shown in Table 5. The TFC value at different roasting temperatures had significant statistical differences. Specifically, as the temperature increased from 80 °C to 140 °C, the TFC value increased. However, when the roasting temperature was further increased to 160 °C, the amount of TFC decreased to 23.19 ± 0.23 mg QE/100 g dw. Similar results were found in experiments by Park and Lee [33], who reported an increase in the TFC value of high-temperature roasted omija fruit extract. It is believed that the phenolic and flavonoid compound bonds are released during roasting due to the breakdown of cell structures [34].

In this study, the AC of the product is related to the TPC and TFC. Therefore, a correlation between bioactive compounds and antioxidant capacity during the roasting process was observed. The highest AC (26.58 ± 0.24 μmol TE/g dw) was achieved when the tea was roasted at 140 °C. However, if the roasting temperature was increased to 160 °C, the AC decreased to 25.89 ± 0.18 μmol TE/g dw, while the lowest AC value (24.21 ± 0.21 μmol TE/g dw) was obtained at 80 °C. These results are consistent with the increase in TPC and TFC at higher heating temperatures and a slight decrease at the highest temperature. Gallegos-Infante et al. [35] reported similar findings, suggesting that the increase in DPPH scavenging activity is due to the Maillard reaction leading to the formation of thermally induced products, enhancing the antioxidant capacity during the heating process.

AC is a measure of antioxidant potential used to evaluate the quality of certain food products, especially tea and beverages. Furthermore, an increase in AC content was observed as the drying temperature increased, which is consistent with the study by Otles and Selek [36]. Similarly, these authors hypothesized that the higher antioxidant capacity during high-temperature roasting may be due to the biodegradation of bioactive compounds and the generation of different products with antioxidant properties of the Maillard reaction. However, Kocadağlı and Gökmen [37] reported that AC increased with roasting temperature up to a certain level and then decreased at higher roasting temperatures, consistent with the findings of the current study.

The studies by Altay et al. [38] and Thamkaew et al. [39] suggest that drying the product at high temperatures and for a relatively long time can lead to a decrease in the content of bioactive compounds as well as changes in other quality parameters such as color, taste, and aroma. Based on the survey results, a roasting temperature of 140 °C was chosen as the suitable temperature for ginger tea processing.

Effect of roasting temperature on the quality of ginger tea

Roasting is an important stage in tea processing. The role of roasting is to evaporate water from the materials and, more importantly, to facilitate reactions at high temperatures. These reactions promote the formation of flavor and color compounds, resulting in a high-quality tea product [40].

The influence of roasting temperature on the color and a_w of the product is demonstrated in Table 6, which shows an increasing trend in the L* value and a decreasing trend in the b* color parameter as the roasting temperature increased from 80 °C to 140 °C. Moreover, the L* value at 140 °C (67.24 ± 0.19) significantly differs statistically from the other temperatures. Wang et al. [41] found that the color of tea changes with the roasting process time, so lower temperatures and longer roasting times lead to decreased color intensity. However, if the temperature is further increased to 160 °C, the L* value decreases to 66.28 ± 0.27. Aydogdu et al. [42] observed that increasing the temperature leads to an increase in the reaction between amino groups and sugars. The Maillard reaction rate increases with temperature, resulting in a decrease in product color. However, this reaction occurring at the right level also contributes greatly to the changes in the aroma, color, and flavor of tea [43].

Table 6

Effect of roasting temperatures on color and water activity of ginger tea

Roasting temperatures (℃)	Color parameters			a_w
	L*	a*	b*	
80	65.35 ± 0.25^{a}	7.01 ± 0.22^{a}	20.91 ± 0.24^{d}	0.49 ± 0.01^{ab}
100	66.70 ± 0.08^{c}	7.79 ± 0.17^{b}	19.15 ± 0.17^{ab}	0.52 ± 0.01^{c}
120	66.85 ± 0.13^{c}	8.01 ± 0.25^{bc}	18.82 ± 0.23^{a}	0.50 ± 0.01^{b}
140	67.24 ± 0.19^{d}	8.35 ± 0.27^{cd}	19.79 ± 0.18^{c}	0.48 ± 0.01^{a}
160	66.28 ± 0.27^{b}	8.56 ± 0.15^{d}	19.56 ± 0.34^{bc}	0.49 ± 0.01^{ab}

Different letters in the same column indicate the significant difference of the survey treatments at 95 % confidence level.

After roasting at different temperatures, the a_w showed a relatively low water activity in the resulting product (ranging from 0.49 to 0.52), which is one of the favorable conditions for preserving ginger tea. However, the roasting process mainly contributes to the aroma and characteristic color of the product. Therefore, a roasting temperature of 140 °C was chosen as the appropriate temperature to give the characteristic color of the product.

Effect of moisture content on ginger tea

Effect of final moisture content on the TPC, TFC, and AC of ginger tea

The moisture content of the product is one of the important factors affecting the obtainment of bioactive compounds in ginger tea bags. The impact of product moisture content on the preservation of biological activities in ginger tea is shown in Table 7.

Table 7

Effect of the final moisture content on the TPC, TFC, and AC of ginger tea

Final moisture content (%)	TPC (mg GAE/g dw)	TFC (mg QE/100 g dw)	AC (µmol TE/g dw)
4	8.78 ± 8.78^{a}	22.73 ± 0.12^{a}	24.58 ± 0.12^{a}
6	9.15 ± 0.14^{ab}	23.17 ± 0.14^{b}	24.93 ± 0.15^{b}
8	9.85 ± 0.18^{c}	25.51 ± 0.18^{d}	27.02 ± 0.17^{d}
10	9.42 ± 0.21^{b}	24.19 ± 0.13^{c}	26.63 ± 0.13^{c}

Different letters in the same column indicate the significant difference of the survey treatments at 95 % confidence level.

The results in Table 7 show statistically significant differences in the levels of bioactive compounds obtained when changing the final moisture content of the ginger tea bag product. Specifically, when increasing the moisture content from 4 % to 8 %, compounds such as TPC, TFC, and AC increased. At a moisture content of 8 %, the TPC (9.85 ± 0.18 mg GAE/g dw), TFC (25.51 ± 0.18 mg GE/100 g dw), and AC (27.02 ± 0.17 µmol TE/g dw) values reached the highest values. At a moisture content of 10 %, the TPC, TFC, and AC decreased to 9.42 ± 0.21 mg GAE/g dw, 24.19 ± 0.13 mg QE/100 g dw, and 26.63 ± 0.13 µmol TE/g dw, respectively. At 10 % moisture content, the reduction in the level of bioactive compounds is due to the presence of a higher amount of water in the product, which leads to larger particle size during grinding and reduces the surface area available for solvent contact, resulting in decreased efficiency of bioactive compound extraction. Achieving moisture contents of 4 % and 6 % requires a longer roasting time compared to 8 %, which can lead to the degradation of bioactive compounds due to prolonged exposure to high temperatures.

Effect of moisture content on the quality of ginger tea

Color is also one of the most important visual attributes of food ingredients, as it influences consumers's acceptability of Maskan [44]. From the results in Table 8, it can be observed that the color of the product increases with moisture content. The L* and b* values at 8 % and 10 % moisture content did not show statistically significant differences. However, moisture content higher than 8 % can lead to microbial contamination. On the other hand, moisture content lower than 8 % can result in reduced sensory quality, as the product becomes brittle, affecting the aroma, flavor, and commercial value. Additionally, the a_w of ginger tea within the range of 0.5–0.49 is suitable for the specifications of dried food (a_w < 0.6), ensuring that the food is safe from bacterial and fungal spoilage as well as biochemical activities [45]. In general, to ensure good color quality, 8 % moisture content was chosen as the final moisture content for ginger tea products.

Table 8

Effect of the final moisture content on color and water activity of ginger tea

Final moisture content (%)	Color parameters			a_w
	L*	a*	b*	
4	65.56±0.28^{a}	9.82±0.24^{b}	21.01±0.14^{b}	0.45±0.01^{a}
6	65.77±0.27^{a}	9.51±0.21^{b}	20.68±0.11^{b}	0.47±0.01^{b}
8	67.14±0.16^{b}	9.64±0.19^{b}	19.89±0.28^{a}	0.48±0.01^{bc}
10	67.25±0.12^{b}	8.38±0.17^{a}	19.81±0.16^{a}	0.49±0.01^{c}

Different letters in the same column indicate the significant difference of the survey treatments at 95 % confidence level.

Materials and methods

Sample preparation

The ginger used for the study was purchased at a garden house in Thuong Thanh Ward, Cai Rang District, Can Tho City. The ginger rhizomes selected for purchase were 8 months old, uniform, and undamaged. Upon arrival, the ginger was peeled, washed to remove impurities, cut into fibers, and used for experiments.

After being purchased, ginger was washed to remove impurities, peeled, and cut into 1-2mm fibers using vegetable slicer (model VC60, dienmay3G, Vietnam). The samples were then soaked in a 2 % citric acid solution at a ratio of 1 : 3 (w/v) for 30 min. After rinsing with clean water, the ginger was blanched at 100 °C for 2 min. Once blanched, the ginger was quickly cooled in cold water and then soaked in a 1 % NaCl solution at a ratio of 1 : 3 (w/v) for 30 min. After soaking, the ginger was drained and dried to the desired moisture content. Then, the ginger was roasted to the required moisture content. Finally, the samples were cooled and ground to obtain ginger tea (particle size is less than 1 mm).

Experimental design

Effect of drying temperature on ginger tea (Exp. 1). After processing and cutting into fibers, the ginger was soaked in a 2 % citric acid solution at a ratio of 1 : 3 (w/v) for 30 min. Then, the ginger was rinsed with clean water and blanched at 100 °C for 2 min. After blanching, the ginger was quickly cooled in cold water and soaked in a 1 % NaCl solution at a ratio of 1 : 3 (w/v) for 30 min. The sample was then taken out and dried at temperatures of 50 °C, 60 °C, 70 °C, and 80 °C until the moisture content reached 60%. Next, the ginger was roasted at 100 ± 2 °C until the moisture content reached 10%. Finally, the sample was cooled and ground to obtain ginger tea. The product was analyzed for color indicators (L*, a*, b*), water activity (a_w), total polyphenol content, total flavonoid content, and the antioxidant activity of the ginger tea.

Effect of moisture content after drying on ginger tea (Exp. 2). After cutting into the fibers, the ginger was soaked in citric acid, blanched, and soaked in salt, similar to Exp. 1. Then, the ginger was dried at the temperature selected in Exp. 1 to moisture levels of 50 %, 55 %, 60 %, and 65 %. After the ginger reached the desired moisture levels, roasting was carried out at 100 ± 2 °C to a product moisture content of 10 %. Next, the sample was cooled and ground to obtain ginger tea. The ginger tea samples were analyzed for color parameters (L*, a*, b* values), water activity (aw), total polyphenol content, total flavonoid content, and antioxidant activity.

Effect of roasting temperature on ginger tea (Exp. 3). After cutting into fibers, the ginger was soaked in citric acid, blanched, soaked in salt, and dried at the temperature selected in Exp. 1 to the moisture level chosen in Exp. 2. Next, the ginger samples were roasted at 80 ± 2 °C, 100 ± 2 °C, 120 ± 2 °C, 140 ± 2 °C, and 160 ± 2 °C until the moisture level of the product reached 10 %. The samples were then cooled and ground to obtain ginger tea. The ginger tea samples were analyzed for color parameters (L*, a*, b* values), water activity (a_w), total polyphenol content, total flavonoid content, and antioxidant activity.

Figure. Ginger tea after grinding and packing

Effect of moisture after (roasting) on the ginger tea (Exp. 4). After cutting into fibers, the ginger was soaked in citric acid, blanched, soaked in salt, and dried at the temperature selected in Exp. 1 to the moisture level chosen in Exp. 2. Next, the ginger samples were roasted at the temperature selected in Exp. 3 to moisture levels of 4 %, 6 %, 8 %, and 10 %. Next, The samples were then cooled and ground to obtain ginger tea (Figure). The color parameters (L*, a*, b* values), water activity (a_w), total polyphenol content, total flavonoid content, and antioxidant activity of the ginger tea products were analyzed.

Methods of analysis

- Moisture content (%) was measured using moisture analyser (Ohaus MB90, USA).
- Water activity (a_w) was measured using water activity analyser (Rotronic HP23, Switzerland).
- Color parameters (L*, a*, b*) were measured using a portable colorimeter (M&A INSTRUMENTS INC NR20XE, China).
- Total polyphenol content (TPC, mg GAE/g dw) was determined by a colorimetric method with gallic acid as the reference standard and Folin-Ciocalteu reagent as the oxidizing agent. The color was measured at 738 nm [11].
- Antioxidant activity (AC, µmol TE/g dw) was determined using the free radical method with standard DPPH (2,2 – Diphenyl- 1- picrylhydrayl) and comparing with trolox, measuring the color change from purple to light yellow at 517 nm [12].
- Total flavonoid content (TFC, mg QE/100 g dw) was determined by a spectrophotometric method at 415 nm, based on the reaction of flavonoid-aluminum complex [13].

Data analysis

Using Statgraphics Centurion 16.2 (USA) and the Excel program, data were analyzed for the degree of variation and significance of difference based on the analysis of variance (ANOVA) to determine if significant differences ($p<0.05$) existed between treatments using least significant difference (LSD). All experiments were carried out in triplicate.

Conclusions

The results of the study lead to the following conclusions. Drying ginger with hot air at a temperature of 60 ± 2 °C to a moisture content of 60 %, followed by roasting at a temperature of 140 ± 2 °C until the product reaches a moisture content of 8 %, has proven to be suitable for preserving biologically active compounds such as TPC, TFC, and AC at high levels, as well as achieving the best sensory quality. These parameters can be applied on a larger scale in ginger tea production technology.

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