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Research article

Selecting a suitable method and conditions for drying galangal (*Alpinia galanga* L.) rhizomes and holy basil (*Ocimum sanctum* L.) leaves based on physical characteristics, bioactive contents and bioactivities

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Abstract

Galangal (*Alpinia galanga* L.) rhizome and holy basil (*Ocimum sanctum* L.) leaves are common herbs used in Asian food. Drying can prolong the shelf life of these herbs; however, different drying methods and conditions can affect their nutritive value. This research investigated the suitability of three drying methods for drying galangal rhizomes and holy basil leaves—tray drying (T), vacuum drying (V) and microwave vacuum drying (MV)using three different temperature conditions for T and V (40°C, 50°C or 60°C) and three different power settings for MV (1,200 W, 1,800 W or 2,400 W). Each plant sample was dried until its moisture content was less than 8% dry weight and then was tested for physical characteristics, bioactive content and bioactivities. The results showed that tray drying galangal rhizomes at 60°C for 3.5 hr and vacuum drying holy basil leaves at 40°C for 6 hr produced less color change (9.58±0.07 and 7.18±0.10, respectively) compared to fresh samples, high contents of total phenolic content (8.63±0.02 and 20.08±0.11, respectively) and total flavonoid content (3.81±0.01 and 16.49±0.05, respectively) with high antioxidant activities and showed anti-diabetic activity (α-glucosidase inhibition). Drying could improve the antioxidant and anti-diabetic activity levels of the galangal rhizomes and holy basil leaves. There were relationships among the color, bioactive compounds and bioactivity levels of the dried galangal rhizomes and holy basil leaves. Therefore, tray drying at 60°C for 3.5 hr and vacuum drying at 40°C for 6 hr were recommended for drying galangal rhizomes and holy basil leaves.

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Introduction

Herbs and spices are used in food for their unique flavor, color and medicinal properties for health benefits, including their antioxidant activity, digestive stimulation, anti-inflammatory, antimicrobial and anticarcinogenic potential (Wojdylo et al., 2007). Edible and inedible herbs naturally contain polyphenolic compounds, which have antioxidant and anti-diabetes activities (inhibitory effects against carbohydrate hydrolysis enzymes, alpha-amylase, and alpha-glucosidase) (Zhang et al., 2015). Rhizomes of galangal (*Alpinia galanga* L.) and leaves of holy basil (*Ocimum sanctum* L.) are commonly used in Asian food. Galangal belongs to the Zingiberaceae family and holy basil belongs to the Lamiaceae family. Both herbs are cultivated throughout India and North and Southeast-Asia including Thailand, Lao and China (Juntachote and Berghofer, 2005). Galangal rhizomes and holy basil leaves not only have unique flavors and tastes but they also provide potential bioactive compounds that are beneficial to health. For example, galangal rhizomes and holy basil leaves contain mostly polyphenol and flavonoid compounds depending on the type of extraction solvent used (Chouni and Paul, 2018). These bioactive compounds could act as antioxidants and have anti-diabetes potential. Ethanol solvent has been reported for extracting bioactive compounds from many plants (Sun et al., 2015).

Freshly harvested herbs and spices contain high amounts of moisture and numerous microorganisms, which potentially lead to biological deterioration after harvesting. Drying is a common preservation method to prolong the shelf life of these products by reducing the moisture content in the raw herbs (Hossain et al., 2010) However, different drying methods and conditions can affect the quality of dried herbs, such as changing the appearance and color and inducing partial or complete losses or even gains in bioactive compounds, which directly affect their bioactivities (Stępień et al., 2019). Common drying processes used in herb preservation include sun drying, convective drying (tray drying), vacuum drying and using a microwave vacuum, where each drying technique has advantages and limitations. For example, in tray drying, forced convectional heating is used to remove moisture from the solids placed on the tray (Parikh, 2014). The shelf life of dried products can be prolonged even when stored at ambient temperature. However, some essential chemicals and nutritional nutrients in the product could be degraded, along with color changes and structure shrinkage due to the effect of the direct heated airflow during drying (Figiel et al., 2010). Vacuum drying involves the mass transfer of the moisture present in plants materials under vacuum pressure (Parikh, 2015). Consequently, vacuum drying can dry a product more rapidly and more efficiently. However, this method requires more complex equipment than other processes. Microwave vacuum drying combines two processes, ionization and polarization interactions. Microwaves convert heat due to the ability of food materials to absorb microwave energy and transform it into heat due to dipolar and ionic mechanisms, with moisture and water causing dipolar rotation because of the dipolar nature of water, whereas the ions cause ionic polarization (Bezyma and Kotovoy, 2005). The puffing phenomenon, which causes food to have a porous texture and reduces its density, results in products dried using this method (Sham et al., 2001).

The objective of the current study was to identify a suitable drying method and conditions by considering the physical characteristics, bioactive content and the antioxidant and antidiabetic activities of galangal rhizomes and holy basil leaves using three different drying methods and conditions. In addition, the relationships were studied among the contents of bioactive compounds and the bioactivities of galangal rhizomes and holy basil leaves extracts. The results should enable producers to apply an effective drying method and conditions for galangal rhizomes and holy basil leaves to prolong their shelf life and to maintain their bioactive properties, especially their antioxidant and antidiabetic activities.

Materials and Methods

Plant materials

Fresh galangal rhizomes and holy basil leaves were purchased from a local Thai market (Pathum Thani province, Thailand) during June and July 2019. The samples of both herbs had good form without any insect damage and were washed in fresh running water for 2–3 min before being used. The galangal rhizomes were hand-cut into slices 1.0–1.5 mm thick. Mature holy basil leaves (2.0–3.5 cm in length) with a consistent light-green color were selected. Each sample was packed in a polyethylene plastic bag and kept in a refrigerator at 5°C for no more than 24 hr before use in the drying experiment.

Chemical reagents

PNPG (2,3,5,6,4-nitrophenyl α-D-glucopyranoside), alpha-glucosidase enzyme, gallic acid (trihydroxybenzoic acid) and Folin-Ciocalteu reagent (sodium 1,2-naphthoquinone-

4-sulfonate) were purchased from Sigma-Aldrich (Buchs, Switzerland). DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical, Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) and acarbose were purchased from Sigma-Aldrich (Steinnheim, Germany). Other standards and analytical solvents were purchased from Carlo Erba Reagent (Chaussée du Vexin, France) or Sigma-Aldrich (Gillingham, UK).

Drying experiments

Precut, fresh galangal rhizomes and selected holy basil leaves were weighed to provide samples of 300 g each and dried under various conditions using three different drying methods: tray drying, vacuum drying and microwave vacuum drying.

Tray drying was performed in a tray dryer (T; BWS model; Frecon; Bangkok, Thailand). Each 300 g of precut galangal rhizome or holy basil leaves was placed in a tray with uniform holes (approximately 0.8 mm in diameter), dried at 40°C, 50°C or 60C (T40, T50 and T60, respectively) with an air flow velocity of 1 m/s. The second drying method, vacuum drying (V), was conducted in a vacuum dryer (March-Cool; Bangkok, Thailand) by placing samples into 20 L cylinders at a pressure of 10 kPa at 40°C, 50°C or 60°C (V40, V50 and V60, respectively). The last drying method, microwave vacuum drying (MW), was performed using a microwave vacuum dryer (March-Cool; Bangkok, Thailand) at magnetron output power levels of 1,200 W, 1,800 W or 2,400 W (MV1200, MV1800 and MV2400, respectively) or microwave intensities of 4.0 W/g, 6.0 W/g or 8.0 W/g, respectively, at a pressure of 13.33 kPa (Therdthai and Northongkom, 2011).

All samples of galangal rhizomes or holy basil leaves after all methods and conditions of drying were sampled (10 g each sampling time), as indicated in Table 1 and then weighed and analyzed for moisture content using the hot-air oven method (Association of Official Analytical Chemists, 1990) until a final moisture lower than 8% dry weight (DW) was recorded. All samples were weighed on an electronic balance with an accuracy of ±0.05 g. The measured time at which a moisture content less than 8% DW was first recorded was selected as the suitable drying time for that drying method under the prescribed conditions. All dried galangal rhizomes and holy basil leaves samples based on the suitable drying time for each method and the respective conditions were ground in a pulverizing machine (RT-N08, Rong Tsong Precision Technology Co.; Taichung City, Taiwan) for 5 min and 1 min, respectively, and stored in vacuum bags at -20°C until they were used in the next experiment. Three replications of experiment were applied for nine treatments.

Plant extraction

Plant extractions were conducted according to the method described by Galani et al. (2017) with some modifications. One gram of dried sample from each treatment was added with 2 mL of 95% ethanol and first shaken for 1 min in a vortex mixer (G-560E, serial#2-101912; Scientific Industries; Bohemia, NY, USA) and then shaken a second time using ultra-sonication at 40°C, 100 W or 80 Hz for 5 min. After that, each extract was centrifuged at 6,000 rpm for 10 min

Table 1 Sampling time of galangal rhizomes and holy basil leaves after drying using different drying methods and conditions

Drying method and conditions	Drying time	
	Galangal rhizome	Holy basil leaf
Tray drying:		
40°C	0, 10, 24, 25, 26, 27, 28 hr	0, 10, 22, 23, 24, 25 hr
50C	0, 5, 12, 13, 14, 15, 16 hr	0, 6, 7, 8, 9 hr
60°C	0, 1, 2, 3, 4, 5 hr	0, 2, 3, 4, 5 hr
Vacuum drying:		
40°C	0, 4, 4.5, 5, 5.5, 6 hr	0, 4, 4.5, 5, 5.5, 6 hr
50C	0, 2, 2.5, 3, 3.5, 4 hr	0, 2, 2.5, 3, 3.5, 4 hr
60°C	0, 1.5, 2, 2.5, 3, 3.5 hr	0, 1, 1.5, 2, 2.5, 3 hr
Microwave vacuum drying[a]:		
40°C	0, 10, 16, 17,18, 19 min	0, 5, 14, 15, 16, 17 min
50C	0, 13, 14, 15, 16 min	0, 9, 10, 11, 12 min
60°C	0, 8, 9, 10, 11 min	0, 5, 6, 7, 8 min

[a]Microwave dryer had to stop after drying for 1 min and was then restarted after waiting 5 min to cool down the magnetron. Drying cycles were repeated for each drying time indicated in the table.

and passed through Whatman filter paper No.1. Subsequently 2 mL of 95% ethanol was added to the pellet for re-extraction using the same method mentioned above. The supernatants of triplicate extraction were combined and mixed with 95% ethanol to a final concentration of 100 mg/mL. The extract solutions were stored in a refrigerator at 4°C until they were analyzed.

Physical analysis

Yield

The yield from each drying process was determined by subtracting the weight of each sample before drying from that after drying for each treatment (Mondal et al., 2019).

Color measurement

Color measurement was defined using a digital spectrophotometer (Model CM-3500d; Minolta; Japan) in the CIE *L*, a** and *b** (CIELAB) color space with a D65 light source (Cal et al., 2006). The color brightness (*L**) measures the whiteness value and ranges from black (0) to white (100). The values *a** and *b** represent greenness (-*a**) to redness (+*a**) and blueness (-*b**) to yellowness (+*b**), respectively. The color difference (ΔE) associated with drying each sample was calculated using fresh material as the color reference.

Bioactive compounds

Total phenolic content analysis

Folin-Ciocalteau reagent (FCR; Ajax Finechem Co. Ltd; Taren Point, NSW, Australia) was used to determine the total phenolic content (TPC) using a spectrophotometer (Thermo Fisher Scientific Co., Ltd, model 4001/4; Waltham, MA, USA) with some modifications (Wolfe et al., 2003). A sample (125 µL) was placed into a tube with deionized water (500 µL) and FCR (125 µL) and allowed to stand for 6 min. Afterward, 7% w/v Na_2CO_3 (1,250 µL) and deionized water (1 mL) were added, the solution was mixed for homogenization, and finally, it was placed in the dark for 90 min. Then, the absorbance was measured using the spectrophotometer at 760 nm. The experiments were conducted with three replications of nine treatments. The TPC was expressed as milligrams of gallic acid equivalents per gram of dried sample (mg GAE/g DW).

Total flavonoid content analysis

The total flavonoid content (TFC) was measured using the colorimetric method from Wolfe et al. (2003) with some modifications. A known concentration of sample solutions (250 µL) was solubilized in deionized water (1,250 µL) in a tube; then, 5% $NaNO_2$ (75 µL) was added. After 5 min, 10% $AlCl_3$ (150 µL) was added. The solution was left to stand for 6 min before 1M NaOH (500 µL) was added. Finally, the mixture was diluted with deionized water (275 µL). The absorbance of this solution was measured using the spectrophotometer at 510 nm and compared to a standard curve of prepared catechin solution. The experiments were conducted with three replications of nine treatments. The TFC was expressed as milligrams of catechin equivalents per gram dried sample weight (mg CE/g DW).

Antioxidant activity

2,2-Diphenyl-1-picryl-hydrazyl-hydrate free radical scavenging assay

The antioxidant activity of the extract solutions was investigated using a 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH) free radical scavenging assay (Fernandes et al., 2016) with some modifications. DPPH was diluted to 0.1 mM with 95% ethanol. Trolox was used as an equivalent source of antioxidation for comparison with extraction solutions from each treatment. For analysis, 2 mL of each extract was separately added to a tube with 2 mL of DPPH. The mixture was shaken and placed in a dark chamber for 60 min. Subsequently, the absorbance was measured using a spectrophotometer at 517 nm. The results were expressed in milligrams of Trolox equivalents per gram of dried sample weight (mg TE/g DW), where a lower absorbance represented a higher level of DPPH free radical scavenging activity. Then, the lowest absorbance of each dried extract solution was chosen as the half-maximal inhibitory concentration (IC_{50}) of that treatment.

Ferric reducing antioxidant power assay

Ferric reducing antioxidant power (FRAP) assay was used to determine the reduction of Fe^{3+} of 2,4,6-tris (2-pyridyl)-s-triazine (TPTZ) to Fe^{2+} of TPTZ (blue color), according to Nguyen et al. (2015). The FRAP reagent was prepared using acetate buffer at pH 3.6 (100 mL), 10 mM TPTZ (10 mL) and 20 mM $FeCl_3.6H_2O$ (10 mL) at a ratio of 10:1:1 (v/v/v), respectively. Then, 12 mL of deionized water was added; the solution was maintained in a water bath at 37°C. For analysis, 60 µL of extract solution and 180 µL of deionized water were pipetted into a tube; then, 1.8 mL of prepared FRAP reagent was added. This solution was maintained in the water

bath at 37°C for 4 min before measuring the ferric reduction by measuring absorbance using a spectrophotometer at 593 nm compared with a FRAP blank. The FRAP value was expressed as micromoles of $FeSO_4$ equivalents per gram of dried sample weight (μmol $FeSO_4$ /g DW), where a higher FRAP value represented a higher level of ferric reducing antioxidant power.

Antidiabetic activity

α-Glucosidase inhibitory assay

The inhibitory action of the plant extracts on α-glucosidase activity was determined according to the method described by Kazeem et al. (2013) with some modifications. First, the extracts from each treatment were diluted with 95% ethanol to 50 mg/mL concentration; then, 100 μL of extract was added to a tube with 500 μL of phosphate buffer (pH 6.8) and 500 μL of 0.05 U/mL α-glucosidase. After pre-incubation for 10 min, 500 μL of 5 mM 4-nitrophenyl-β-D-glucopyranoside (pNPG), dissolved in 100 mL of 0.1 M phosphate buffer, was added as a substrate to start the reaction. Then, the mixture was incubated at 37°C for 30 min, after which 2 mL of 0.2 M Na_2CO_3 and 4 mL of reverse osmosis water were added to stop the reaction. After that, the samples were measured using the spectrophotometer (at 405 nm) for the yellow color of para-nitrophenol that had been released from pNPG. The results were expressed as the percentage inhibition, where a lower absorbance represented a higher level of α-glucosidase inhibitory power. The plant extract from each drying treatment with the highest anti-α-glucosidase activity was selected to determine the 50% inhibition level of α-glucosidase activity (IC_{50}). Acarbose was used as a positive reference.

The experiments were conducted following a completely randomized design with nine treatments in triplicate.

Statistical analysis

Data were analyzed using analysis of variance. Wherever *F*-values were significant, mean comparisons were performed using Duncan's new multiple range tests. Pearson's correlation coefficient (r^2) was calculated to evaluate the relationships between bioactive compounds and their bioactivities. The tests were considered significant at $p \leq 0.05$ and highly significant at $p < 0.01$. The statistical analysis was conducted using the SPSS (ver. 23) software (Chicago, IL, USA).

Results and Discussion

Effects of drying method on physical characteristics of plants

To achieve a moisture content of less than 8%, the galangal rhizomes were dried using a tray dryer at 40°C (T40), 50°C (T50) or 60°C (T60) for at least 27 hr, 14 hr and 3.5 hr, respectively, dried using a vacuum dryer at 40°C (V40), 50°C (V50) or 60°C (V60) for at least 7 hr, 4 hr and 3 hr, respectively, and dried using a microwave vacuum dryer at 1,200 W (MV1200), 1,800 W (MV1800) or 2,400 W (MV2400) for at least 18 min, 15 min, and 9 min, respectively. Holy basil leaves were dried using the same methods and temperatures or microwave power levels as for the galangal rhizomes; however, the drying time applied to achieve a moisture content of less than 8% for the holy basil leaves was less than for the galangal rhizomes due to their structural differences. The drying times for the holy basil leaves using the tray dryer at 40°C, 50°C or 60°C were 24 hr, 7.5 hr, and 3 hr, respectively, using the vacuum dryer at 40°C, 50°C or 60°C were 6 hr, 3 hr and 2 hr, respectively, and using the microwave vacuum dryer at 1,200 W, 1,800 W and 2,400 W were 16 min, 10 min, and 7 min, respectively. The higher the microwave power, the shorter the drying time required. Among these three drying methods, tray drying had a faster rate of diffusion that resulted in heat penetrating the surface into the interior of the sample and the rate of evaporation of water on the surface was faster than the rate of diffusion to the surface (Danso-Boateng, 2013). Vacuum drying could remove moisture under sub-atmospheric pressure, which allowed more water to evaporate compared with hot-air drying at the same drying temperature, so a shorter drying time could be used (Jaya and Das, 2003). Microwave vacuum drying depended on the microwave power; however, theoretically, it should have the shortest dry time because this method had a faster heat transfer to a greater depth than either tray drying or vacuum drying (Therdthai and Zhou, 2009).

The current results showed that galangal rhizomes dried using the microwave vacuum dryer at 1,200 W for 18 min (MV1200, 18 min) had the highest drying yield (10.77% yield) but this was not significantly higher than from tray drying at 40°C for 27 hr (10.76% yield). The holy basil leaves dried using the vacuum dryer at 50°C for 3 hr had the highest yield (15.82%) and this was significantly different from other treatments. Dried holy basil leaves had higher yields than dried galangal rhizomes for the same treatment. This may have been due to their structural differences that resulted in the holy basil leaves using less heating time to reach < 8% moisture content

than for the galangal rhizomes at the same heating temperature. However, tray drying at 40°C, vacuum drying at 50°C and microwave vacuum drying at 1,200 W produced the highest yields among the same drying methods for each herb (Table 2).

The different pigments present in the galangal rhizomes compared to the holy basil leaves were responsible for the color difference. The fresh galangal rhizomes were a yellow color due to flavonoids, galangin and kaempferol, whereas the fresh holy basil leaves were a green color from the chlorophyll. The flavonoids in the galangal rhizomes were more heat-stable compared to the chlorophyll in the holy basil leaves (Sharma et al., 2015). In addition, the structure of the holy basil leaves was finer and less dense than the structure of the galangal rhizomes. The results showed that as the drying temperature of the tray dryer or the vacuum dryer increased, the ΔE value (the color difference from a fresh sample) of the holy basil leaves increased significantly in contrast with the ΔE values for the galangal rhizomes decreased significantly. These results may have been due to differences in their structures and color pigments. To preserve color (minimizing ΔE), the galangal rhizomes should be dried at a high heat for a short drying time (T60 for 3.5 hr or V60 for 3 hr), while the holy basil leaves should be dried at a low heat for a long drying time (T40 for 24 hr or V40 for 6 hr). However, microwave vacuum drying for both the galangal rhizomes and holy basil leaves should use a low power level for a long drying time (MV1200 for 18 min for the galangal rhizomes and MV1200 for 16 min for the holy basil leaves). In addition, the criteria for selecting a suitable drying method and conditions for drying galangal rhizomes and holy basil leaves should consider the impact on the preserved bioactivities.

Effects of drying methods and conditions on bioactive compounds and bioactivities

Bioactive compounds of galangal rhizomes and holy basil leaf extracts

Phenolics and flavonoids are common bioactive compounds found in galangal rhizomes and holy basil leaves. In the current study involving dried galangal rhizomes and holy basil leaves, ethanol was used for plant extraction based on major bioactivities such as acetoxy chavicol acetate pinocembrin, catechin, eugenol, p-coumaryl-9-mthyle, galangin and kaempferide (Zhang et al., 2015). These phenolics and flavonoids are

Table 2 Yield and color characteristics of galangal rhizomes and holy basil leaves after drying

Herb	Drying conditions	Yield (%)	Colour values			
			*L**	*a**	*b**	ΔE
Galangal rhizomes	Fresh	-	66.10±0.07^{i}	0.55±0.03^{i}	17.76±0.05^{e}	-
	T40 (27 hr)	10.76±0.69^{a}	73.77±0.03^{f}	7.67±0.02^{b}	22.47±0.01^{b}	11.46±0.02^{d}
	T50 (14 hr)	9.82±0.01^{d}	74.51±0.03^{e}	5.24±0.02^{d}	21.24±0.48^{c}	10.19±0.13^{e}
	T60 (3.5 hr)	10.35±0.21^{c}	75.74±0.06^{d}	0.47±0.01^{i}	18.88±0.06^{d}	9.58±0.07^{f}
	V40 (7 hr)	9.79±0.45^{e}	78.63±0.04^{a}	2.66±0.01^{f}	19.04±0.07^{d}	12.68±0.04^{a}
	V50 (4 hr)	10.53±0.04^{b}	78.21±0.06^{b}	2.18±0.03^{h}	19.13±0.05^{d}	12.20±0.05^{c}
	V60 (3 hr)	9.97±0.31^{d}	77.30±0.08^{c}	2.33±0.06^{g}	19.21±0.14^{d}	11.34±0.10^{d}
	MV1200 (18 min)	10.77±0.78^{a}	71.14±0.03^{h}	7.06±0.07^{c}	22.80±0.24^{a}	9.66±0.18^{f}
	MV1800 (15 min)	10.58±0.14^{b}	72.81±0.02^{g}	8.69±0.10^{a}	22.18±0.11^{b}	11.46±0.12^{d}
	MV2400 (9 min)	10.44±0.00^{c}	78.27±0.04^{b}	3.34±0.02^{e}	18.07±0.10^{e}	12.42±0.04^{b}
Holy basil leaves	Fresh	-	41.64±0.02^{f}	−9.06±0.02^{h}	22.12±0.02^{h}	-
	T40 (24 hr)	14.92±0.07^{c}	47.93±0.02^{e}	−4.87±0.08^{d}	27.99±0.08^{e}	9.46±0.08^{d}
	T50 (7.5 hr)	14.87±0.21^{cd}	50.56±0.07^{c}	−3.17±0.02^{c}	29.33±0.02^{d}	12.77±0.05^{c}
	T60 (3 hr)	14.74±0.04^{d}	53.30±0.03^{a}	−7.49±0.04^{g}	32.80±0.08^{a}	15.70±0.07^{a}
	V40 (6 hr)	14.73±0.42^{d}	38.80±0.03^{h}	−2.80±0.12^{b}	22.42±0.15^{g}	7.18±0.10^{h}
	V50 (3 hr)	15.82±0.71^{a}	37.91±0.01^{i}	−2.79±0.03^{b}	20.20±0.03^{j}	7.83±0.02^{g}
	V60 (2 hr)	15.59±0.07^{b}	40.05±0.07^{g}	−1.30±0.01^{a}	25.24±0.08^{f}	8.76±0.02^{e}
	MV1200 (16 min)	14.87±0.64^{cd}	36.82±0.03^{j}	−2.76±0.04^{b}	20.73±0.06^{i}	8.38±0.04^{f}
	MV1800 (10 min)	13.24±0.01^{e}	50.40±0.05^{d}	−6.86±0.01^{f}	31.49±0.04^{b}	12.86±0.06^{c}
	MV2400 (7 min)	12.92±0.10^{f}	51.40±0.03^{b}	−5.90±0.04^{e}	31.10±0.04^{c}	13.47±0.04^{b}

*L**, *a** and *b** = color properties based on CIELAB color space; ΔE = color differences; T40–T60 = tray drying at 40°C, 50°C or 60°C; V40–V60 = vacuum drying at 40°C, 50°C or 60°C; MV1200–MV2400 = microwave-vacuum drying at 1,200 W, 1,800 W or 2,400 W

Mean (± SD) values in a column superscripted with different lowercase letters indicate significant ($p \leq 0.05$) differences within each plant.

known for their potential antioxidant activities and free radical scavenging abilities. For the current study, the effects of drying method and the associated conditions on the TPC and TFC of galangal rhizomes and holy basil leaves are shown in Table 3. The drying effects on the TPC and TFC levels had the same trend in both plants as for ΔE. As the temperature increased in tray drying and vacuum drying, the TPC and TFC levels of galangal rhizome increased significantly but for the holy basil leaves it decreased significantly. Preservation of the TPC and TFC levels in the dried galangal rhizomes and holy basil leaves would require the same conditions as mentioned regarding Δ*E*. Normally, phenolic acid compounds occur in plants as metabolic intermediates; they usually accumulate and are enclosed by a membrane (Raksakantong et al., 2012). For the galangal rhizomes, it could be assumed that heat treatment at 60C might increase the amount of bound phenolic compounds due to the breakdown of cellular constituents; therefore, degradation of polyphenol compounds by the thermal process may result in the release of antioxidant compounds with various chemical and biological properties. In contrast to the galangal rhizomes, for the dried holy basil leaves increasing the temperature in all drying methods caused the TPC and TFC levels to decrease. This might have been due to the degradation of volatile compounds and bioactive substances. To obtain high levels of TPC and TFC, the results suggested that using tray drying at 60°C for 3.5 hr and vacuum drying at 40°C for 6 hr were suitable for drying the galangal rhizomes and holy basil leaves, respectively.

Antioxidant activity of galangal rhizomes and holy basil leaves extract

Similar trends to those for the TPC and TFC levels were observed for the effects of drying method and conditions on the DPPH free radical scavenging and FRAP reducing power of galangal rhizomes and holy basil leaves. The highest DPPH and FRAP values were obtained from tray drying at 60°C for 3.5 hr and vacuum drying at 40°C for 6 hr for galangal rhizomes and holy basil leaves, respectively. In addition, the IC_{50} value from DPPH free radical scavenging for galangal rhizomes tray-dried at 60°C was 4.31 ± 0.06 mg/mL, which was lower than that of fresh equivalents (7.74 ± 0.02 mg/mL), as shown in Table 3; thus, galangal rhizomes had improved antioxidant activity after drying. Another study also showed that radical scavenging activity increased with higher drying temperatures (Vega-

Table 3 Effects of drying methods and conditions on bioactive compounds and bioactivities

Herbs	Drying Conditions	TPC (mg GAE/g DW	TFC (mg CE/g DW)	DPPH (mg TE/g DW)	FRAP (μmol FeSO4/g DW)	α-Glucosidase inhibition (%)
Galangal rhizomes	T40 (27 hr)	5.82±0.04^{e}	2.00±0.01^{f}	1.40±0.00^{d}	19.71±0.79^{g}	41.10±0.94^{b}
	T50 (14 hr)	6.57±0.03^{d}	2.72±0.09^{d}	1.68±0.01^{b}	23.48±0.41^{d}	51.47±1.07^{a}
	T60 (3.5 hr)	8.63±0.02^{a}	3.81±0.01^{a}	2.80±0.04^{a}	36.92±0.82^{a}	52.01±0.33^{a}
	V40 (7 hr)	6.39±0.01^{d}	2.73±0.07^{d}	1.21±0.01^{e}	23.27±0.91^{d}	45.10±0.07^{b}
	V50 (4 hr)	6.91±0.01^{c}	3.28±0.04^{c}	1.52±0.02^{c}	28.91±0.38^{b}	50.33±1.02^{a}
	V60 (3 hr)	7.52±0.04^{b}	3.59±0.07^{b}	1.72±0.00^{b}	30.96±0.43^{b}	51.21±0.68^{a}
	MV1200 (18 min)	7.11±0.02^{c}	2.21±0.01^{e}	1.39±0.01^{d}	25.88±0.23^{c}	40.84±0.80^{b}
	MV1800 (15 min)	5.90±0.03^{e}	1.80±0.04^{g}	1.19±0.02^{e}	20.43±0.34^{e}	38.82±0.85^{c}
	MV2400 (9 min)	5.23±0.04^{f}	1.74±0.01^{g}	0.71±0.00^{f}	16.80±0.19^{f}	32.74±0.17^{d}
Holy basil leaves	T40 (24 hr)	17.20±0.25^{b}	12.42±0.27^{bc}	6.43±0.03^{b}	144.75±0.56^{b}	46.05±0.86^{b}
	T50 (7.5 hr)	15.86±0.10^{b}	10.40±0.30^{cd}	2.01±0.01^{e}	105.76±0.88^{d}	31.64±0.44^{d}
	T60 (3 hr)	6.32±0.21^{e}	5.83±0.12^{ef}	1.33±0.01^{fg}	65.54±0.97^{f}	21.59±0.53^{e}
	V40 (6 hr)	20.08±0.11^{a}	16.49±0.05^{a}	8.36±0.07^{a}	163.74±0.77^{a}	53.43±0.87^{a}
	V50 (3 hr)	15.65±0.54^{b}	13.93±0.32^{ab}	5.74±0.08^{c}	110.30±0.69^{c}	43.38±0.29^{b}
	V60 (2 hr)	7.87±0.07^{de}	6.35±0.11^{e}	4.03±0.03^{d}	97.73±0.86^{e}	34.00±0.07^{c}
	MV1200 (16 min)	17.71±0.04^{ab}	11.31±0.18^{bc}	1.59±0.00^{ef}	49.30±0.36^{g}	37.13±0.44^{c}
	MV1800 (10 min)	12.74±0.01^{c}	6.00±0.10^{ef}	0.85±0.01^{gh}	31.47±0.40^{h}	30.39±0.51^{d}
	MV2400 (7 min)	8.43±0.04^{d}	4.30±0.06^{f}	0.59±0.01^{h}	27.70±0.53^{h}	23.18±0.34^{e}

T40–T60 = tray drying at 40°C, 50°C or 60°C; V40–V60 = vacuum drying at 40°C, 50°C or 60°C; MV1200–MV2400 = microwave vacuum drying at 1,200 W 1,800 W (MV1800) or 2,400 W; GAE = gallic acid; CE = catechin; TE = trolox equivalent; TPC = total phenolic content; TFC = total flavonoid content; DPPH = (2,2-diphenyl-1-picryl-hydrazyl-hydrate) free radical scavenging; FRAP = ferric reducing antioxidant power

Mean (± SD) values in a column superscripted with different lowercase letters indicate significant ($p \leq 0.05$) differences within each plant.

Gálvez et al., 2012). This might have been due to the phenolic compounds, which were revealed as the main compounds involved in antioxidant activity, being released by the rupture of cell walls (Lou et al., 2015). DPPH free radical scavenging of dried galangal extracts has also been reported to produce different antioxidant activity levels according to different preparation methods (Basri et al., 2017). The IC_{50} values of DPPH free radical scavenging for dried holy basil leaves using vacuum drying at 40°C for 6 hr and fresh leaves were 0.57 ± 0.05 mg/mL and 2.88 ± 0.02 mg/mL, respectively. The antioxidant activity levels of both dried galangal rhizomes and holy basil leaves improved from their fresh forms. In addition, the holy basil leaves had greater antioxidant activity than the galangal rhizomes in both fresh and dried forms, as shown in Table 4.

Potential α-glucosidase inhibition of galangal rhizome and holy basil leaf extracts

Potential antidiabetic activity was estimated using α-glucosidase inhibitory assay. The results are presented in Table 3. A similar trend was observed to those for the levels of TPC, TFC, DPPH and FRAP. The best drying methods and conditions for galangal rhizomes and holy basil leaves were tray drying at 60°C for 3.5 hr (52.01 ± 0.33% α-glucosidase inhibition) and vacuum drying at 40°C for 6 hr (53.43 ± 0.87% α-glucosidase inhibition), respectively, which produced the highest inhibition at the same concentration of extracts (50 mg/mL). The strongest inhibitory activity was confirmed using the IC_{50} values, as shown in Table 3. The IC_{50} values of the galangal rhizomes tray dried at 60°C and of fresh rhizomes were 69.77 ± 0.19 mg/mL and 99.91 ± 0.07 mg/mL, respectively. Holy basil leaves vacuum dried at 40°C and fresh leaves had IC_{50} values of 61.16 ± 0.53 mg/mL and 91.91 ± 0.90 mg/mL, respectively. Thus, drying tended to improve the estimated anti-diabetic activities of the galangal rhizomes and holy basil leaves. However, the activity levels of both dried plants were not comparable to that of the standard acarbose, which had an IC_{50} value of 17.97 ± 0.01 mg/mL. Based on other research, the percentages of inhibitory activity of *Inula viscosa* L. root and the aerial part of *Mimosa pudica* L. were 5.2 ± 0.01% (Orhan et al., 2017) and 0.9 ± 2.61% (Tunna et al., 2015), respectively, with both these being lower levels of inhibitory activity than for the galangal rhizomes and holy basil leaves.

Relationships among color, bioactive compounds and bioactivities of dried galangal rhizomes and holy basil leaves

Analyses of the relationships between the color and *in vitro* bioactivities, shown in Table 5, revealed significant correlations between the values of a^* and TPC, TFC, DPPH, FRAP and α-glucosidase inhibition for the dried galangal rhizomes. For the dried holy basil leaves, correlations were found between the values of ΔE and TPC, TFC, DPPH, FRAP and α-glucosidase inhibition. Specifically, when the values of a^* for the dried galangal rhizomes or ΔE for the dried holy basil leaves decreased, the values of TPC, TFC, DPPH, FRAP and α-glucosidase inhibition increased significantly. In addition, the values of TPC and TFC had significant relationships with DPPH, FRAP and α-glucosidase inhibition for both the dried galangal rhizomes and holy basil leaves; when the levels of the TPC and TFC increased, antioxidant activities (DPPH and FRAP) and anti-diabetes activity (α-glucosidase inhibition) increased. For both plants, there was a stronger relationship between α-glucosidase inhibition and TFC than for α-glucosidase inhibition and TPC as was also reported by Merouane et al. (2019). In another study, the flavonoid compounds identified in galangal rhizomes included pinocembrin, 3-O-methylgalagin, galangin and kaempferide (Zhang et al., 2015) and those in holy basil leaf extract included orientin, vicenin, ursolic acid, luteolin and molludistin (Subramanian et al., 2014).

Table 4 Anti free-radical activity and α-glucosidase inhibitory activity of extracts from fresh and dried galangal rhizome and holy basil leaves using suitable conditions

Sample	IC_{50} (mg/mL)	
	DPPH	α-Glucosidase
Fresh galangal rhizomes	7.74±0.02[a]	99.91±0.07[a]
Dried galangal rhizomes	4.31±0.06[b]	69.77±0.19[b]
Fresh holy basil leaves	2.88±0.02[c]	91.91±0.07[c]
Dried holy basil leaves	0.57±0.05[d]	61.16±0.53[d]
Vitamin C	0.004±0.00[f]	-
Acarbose	-	17.97±0.01[e]

IC_{50} = Half-maximal inhibitory concentration; DPPH = 2,2-diphenyl-1-picryl-hydrazyl-hydrate

Mean (± SD) values in a column superscripted with different lowercase letters indicate significant ($p \leq 0.05$) differences within each plant.

(-) Not measured

Table 5 Pearson's correlation coefficients for correlations among color properties, bioactive compounds and bioactivity assays for dried galangal rhizomes and holy basil leaves

Sample		*L**	*a**	*b**	Δ*E*	TPC	TFC	DPPH	FRAP	*α-glucosidase*
Dried galangal rhizome	*L**	1								
	*a**	-.787**	1							
	*b**	-.919**	.898**	1						
	Δ*E*	.681**	-.112	-.426*	1					
	TPC	-.023	-.555**	-.182	-.629**	1				
	TFC	.400*	-.786**	-.487*	-.257	.872**	1			
	DPPH	-.082	-.466*	-.109	-.669**	.908**	.795**	1		
	FRAP	.111	-.638**	-.292	-.502**	.979**	.922**	.887**	1	
	AG[1]	.194	-.532**	-.204	-.352	.774**	.896**	.768**	.797**	1
Dried holy basil leaves	*L**	1								
	a*	-.815**	1							
	*b**	.974**	-.802**	1						
	Δ*E*	.157	-.177	.044	1					
	TPC	-.342	.525**	-.291	-.667**	1				
	TFC	-.026	.210	.092	-.757**	.890**	1			
	DPPH	.175	.006	.310	-.757**	.588**	.820**	1		
	FRAP	.377	-.026	.471*	-.595**	.571**	.795**	.928**	1	
	AG[1]	-.112	.256	-.001	-.874**	.833**	.918**	.914**	.817**	1

L, a** and *b** = color properties based on CIELAB color space; Δ*E* = color differences; TPC = total phenolic content; TFC = total flavonoid content; DPPH = 2,2-diphenyl-1-picrylhydrazyl; AG = α-glucosidase inhibitory activity; FRAP = ferric reducing antioxidant power

[1]Values of *α-glucosidase* were presented as percentages in 50 mg/mL extract.

*, ** = Significant correlations within each plant at $p \leq 0.05$ and $p \leq 0.01$, respectively

Based on these results, tray drying at 60C for 3.5 hr and vacuum drying at 40°C for 6 hr were recommended for drying galangal rhizomes and holy basil leaves, respectively. These methods and conditions produced better yields, less color change relative to fresh equivalents, higher TPC and TFC levels and greater antioxidant and antidiabetic activities. There were relationships among the color, bioactive compounds and bioactivities of dried galangal rhizome and holy basil leaves. The results of this study should enable producers to apply the identified effective drying method and conditions not only to extend the shelf life of galangal rhizomes and holy basil leaves but also to preserve their health-related bioactive properties, such as antioxidant and antidiabetic activities.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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