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Drying Ginger and Preserving 6-Gingerol

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DOI 10.5073/jka.2018.463.086

Abstract.

Ginger rhizome (*Zingiber officinale*) is widely used as a spice or as a medicinal plant. The major bioactive compound in fresh ginger rhizome is 6-gingerol and it is known for having a number of physiological effects. This compound is heat-sensitive and during cooking or drying will transform into 6-shogaol. Hence, the 6-gingerol content is used to evaluate the quality of dried ginger. The content of 6-gingerol during drying was measured using HPLC. Several factors that could affect the 6-gingerol content were considered and a predictive model for changes in 6-gingerol has been developed from the experimental data. The predictive model includes a single term drying model that predicts the changes of moisture content during drying. Drying time and relative humidity (ranging from 10% to 40%) impacted 6-gingerol content whereas drying air temperature (ranging from 30°C to 60°C) had a lesser effect. It was also found that the 6-gingerol content in fresh rhizomes was highly variable and thus required thorough testing prior to drying to be able to make the prediction more accurate.

Keywords: ginger, air drying, 6-gingerol, HPLC, predictive model.

1. Introduction

Background

Ginger, with a scientific name of *Zingiber officinale* Rosc, is a member of the tropical and sub-tropical family Zingiberaceae. It originates in tropical rainforests in southern Asia and spread to Mediterranean regions by the 1st century. In ancient Rome, ginger was a popular spice used to make delicacies. Throughout the history of global trade, ginger has been traded longer than most other spices. In the ancient world, it was regarded as a costly herb for its medicinal merits and nutritional value.

Over the long history of ginger trading around the world, ginger has been planted on most continents. Given different growing environment, ginger has developed into several cultivars. In commercial trading, ginger is often designated by the country where it originates from, such as Chinese ginger, Indian ginger, Australian ginger or Jamaican ginger. However, ginger has a large cultivar diversity, so that even in one country, there could be dozens of cultivars. Generally, a cultivar comes from a specific growing place, and hence many cultivars were named after their growing place.

Chemical composition of ginger

Ginger rhizomes contain a variety of compounds. Researchers have found more than one hundred compounds which can be classified into three groups: essential oils, gingerol and diarylheptanoids.

Essential oils are hydrophobic liquids, containing volatile chemical constituents. Distillation and extractions are the most common ways to isolate the essential oils. The major components of essential oils are the terpenoids, including monoterpenes and hemiterpenes. Most compounds from these two groups have a strong volatile aroma and biological activity, which are important ingredients in medicine, cosmetics and food production.

Gingerols are major pungent constituents of ginger which are made up of several different compounds. Gingerols have a 4-hydroxy-3-methoxyphenyl group in the chemical structure, varying according to different aliphatic chains attached to the main group. Gingerols can be classified as gingerol, shogaol, gingerdione and gingerdiol.

Gingerols are thermally labile due to the presence of a β-hydroxy keto group in the structure and produce corresponding shogaols via a dehydration reaction (Bhattarai, 2001). The dehydration process will be affected by drying air temperature and residence time. It is reported that raising the reaction temperature and extending time significantly increased the conversion of 6-gingerol to 6-shogaol (Kou et al., 2017). Among gingerols, 6-gingerol has been studied more thoroughly compared to other gingerols such as 8-gingerol and 10-gingerol. This is because the proportion of 6-gingerol in fresh ginger is the highest among all gingerols.

Effects of ginger on human health

Among all of the compounds in ginger, essential oils play an important role in improving consumers' mood. The benefits of ginger essential oils include offering a warm, spicy aroma which enhances feelings of vitality, promotes feeling of physical well-being, and helps improve body blood circulation. It is a frequent addition to blends for massage, arthritis and muscle aches and pains. Ginger oil is commonly used to soothe, comfort and balance digestive discomfort. Gingerols may make a contribution towards human health effects in medical applications of ginger. Studies have shown antitumor activity of 6-gingerol（Parket al., 1998), analgesic and anti-inflammatory effects (Young et al., 2005), and 10-gingerol and 12-gingerol have antibacterial activity against periodontal bacteria (Park et al., 2008). The content of gingerols varies significantly with ginger varieties and cultivating locations.

Use of ginger and derived products

Ginger is used as a main ingredient in many products throughout the world. Fresh ginger roots are juicy with a mild taste and can be used as spices for sweet or salty food such as soup, meat, vegetable, seafood, pickle, curries, drinks and cake. However, due to the strong pungent flavour of fresh ginger root, fresh ginger is normally dried, and used to produce ginger powder, which makes the spicy flavour weaker. Yet, the major use of ginger is in the pharmaceutical area. In many Asian countries, especially China, India and Japan, ginger is treated as one of the additives in traditional medicine, rather than as herb. Therefore, ginger is considered as herbal medicine with strong health benefits.

Dried ginger and dried ginger products account for the largest amount of ginger consumption around the globe, as fresh ginger is mainly produced in tropical and subtropical countries. Dried ginger significantly lowers the cost of transporting and storing. Generally, dried ginger is produced from fresh mature ginger rhizomes whereas immature ginger rhizomes are processed to make preserved ginger, as the mature rhizome has stronger flavour and aroma.

Aim of this study

The aim of this study was to investigate the ability of a two-layer drying model to predict the optimum conditions for drying fresh ginger rhizomes for the maximisation of the retention of 6-ginerol in the dried ginger.

2. Materials and Methods

Ginger samples

The samples of fresh ginger rhizomes were obtained from Buderim Ginger Pty Ltd in Yandina, Queensland, Australia. They were shipped to Sydney in a refrigerated container and then placed in

a freezer at -20°C until being used for experiments. The day before the experiments the samples were defrosted overnight in a fridge at +4°C.

Defrosted ginger rhizomes were peeled and sliced to 5 mm thickness using a slicer. A sample of about 10 g of slices was used for determination of initial moisture content. Duplicate samples were placed in a convection oven at 105°C for 24 h.

Drying

The drying experiments were conducted in a cabinet dryer constructed in the workshop of the School of Chemical Engineering of the University of New South Wales. The cabinet dryer (see Fig. 1) had an electric heater (15 kW) fitted with a PID controller and a fan (0.75 kW). The airflow was parallel to the tray on which the drying samples were placed in a thin layer. The temperature and relative humidity were monitored and recorded with a datalogger. The weight loss was recorded with an electronic balance placed under the sample holding tray.

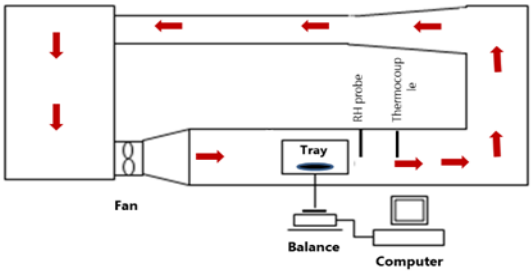

Fig. 1 Cabinet dryer.

The drying conditions in the experiments were either a constant temperature and relative humidity (RH), as in Runs 1-3, or a changing temperatue and RH, as in Runs 4-11 (see Tab. 1).

The reason for this experimental design was that drying temperature was expected to affect the drying process. Since the properties of the ginger samples were changing during the drying process, a change of the drying conditions in the dryer was allowing for investigation of the effects of the changed conditions on the drying behavior of the samples.

The wet sample of sliced rhizome was placed on the tray as quickly as possible in order to reduce the influence of ambient conditions on those in the drying chamber.

After the weight of the sample became steady, i.e., the sample reached the equilibrium moisture content corresponding to the drying conditions (temperature and RH), the drying run was finished. A duplicate dried sample (10 g each) was taken and used for the determination of the final moisture content.

The remainder of the dried sample was weighed and preserved in a vacuum-sealed bag. It was kept in a cool place for the determination of the 6-gingerol content.

Determination of 6-gingerol

The 6-gingerol standard (≫ 98% purity) was obtained from Sigma-Aldrich. Methanol of HPLC grade was purchased from Burdick & Jackson. Water for HPLC analysis was purified with a Milli-Q water system. Agilent vials for HPLC with caps were used. Whatman filter paper had a pore size of 0.45 µm.

Dried ginger slices were pulverized using a grinder and passed through a 40 mesh (0.42 mm) sieve before extraction. In contrast, the fresh ginger was crushed with a mortar and pestle prior to extraction. The sample of ginger powder or paste (1 g) was dissolved in 25 mL HPLC-grade methanol and sonicated for 30 min. The mixtures were centrifuged at 10000 rpm for 10 min and supernatant

was filtered through Whatman filter paper. Then the supernatant was diluted with water to reach a final concentration of 10% methanol and 90% water. Extracts of ginger were transferred to the HPLC vials and capped. All the extracts were kept at 4°C until being used.

Tab. 1 Summary of drying conditions.

Run number	Temperature (°C)	RH (%)
1	40	30
2	50	20
3	60	10
4	60	10
	50	20
5	60	10
	50	30
6	60	10
	50	40
7	60	10
	40	30
8	60	10
	30	40
9	50	30
	40	30
10	50	20
	60	10
11	40	30
	50	20

From Run 4 to Run 11, the drying conditions were changed from those in the 1st rows to those in the 2nd rows when the sample had lost 50% of its weight.

For the calibration curve of 6-gingerol, a stock solution of 5.0 mg/mL of standard in HPLC-grade methanol was prepared. Serial standard dilutions were made from the stock solution to obtain concentrations of 5.0, 10.0, 20.0, 40.0, 60.0 and 80.0 µg/mL. All dilutions of 6-gingerol standard were capped and stored at 4°C.

The HPLC system used in this study was from Shimadzu, model Prominence LC-20AD. The separation of the compounds was conducted in a C18 column (XTerra), 3.5 µm, and 2.1×150 mm. Water (A) and methanol (B) constituted the mobile phase for the separation. The following linear gradient was used: 0-5 min, 50% B; 5-10 min, 50-60% B; 10-15min, 60% B; 15-25min, 60-80% B; 25-30 min, 80% B; 30-35min, 80-50% B; 35-50 min, 50% B. The injection volume was 20 µL and the flow rate was 0.2 mL/min. The detection wavelength of the UV detector (0~1000 nm) was set at 281 nm and the column temperature was maintained at 30°C. The tests were done in triplicate.

3. Results

Content of 6-gingerol in dried samples

Prior to the drying experiments, 6-gingerol content of fresh ginger rhizomes was determined and found to be on average 0.59 ± 0.06 µg/mg 6-gingerol on dry matter basis.

Tab. 2 shows the summary for three constant drying conditions and multiple comparisons while Tab. 3 shows the results of the statistical analysis of the samples (ANOVA). There was a considerable variability within the results of each treatment as indicated by the value of the coefficient of variation (CV). It appears that the highest 6-gingerol content in a dried sample (0.456 µg/mg) was obtained after drying at 50°C and 20% RH. This was far below the initial content in fresh sample (0.5 µg/mg). From the ANOVA test, see Tab. 3, the 6-gingerol content from the three runs was significantly different from each other. Run 2 showed a higher 6-gingerol content than Run 1. This was expected since the drying temperature in Run 2 was higher and the drying time shorter.

However, a considerably shorter drying time in Run 3 did not necessarily result in a higher 6-gingerol content.

Tab. 2 Characteristics of samples subjected to different drying treatments with constant temperature and relative humidity.

Run	Drying conditions	Drying time (min)	6-gingerol content* (µg/mg)	CV (%)
1	40°C 30% RH	314	0.337	9.52
2	50°C 20% RH	293	0.456	4.57
3	60°C 10% RH	154	0.444	3.43

*Average of three experiments

Tab. 3 ANOVA test between constant drying conditions runs

Run comparison	P value
1 vs 2	0.000
1 vs 3	0.000
2 vs 3	0.360

ANOVA, P=0.05

Tabs. 4 and 5 show the summary for eight changing drying conditions and multiple comparisons. In general, the following trend in 6-gingerol content was observed: higher drying temperature and longer drying time resulted in lower gingerol content. This corresponds to the conclusions from the study of Bhattarai et al. (2001) that higher temperature results in rapid and faster dehydration of 6-gingerol and forming of the degradation product, 6-shogaol.

It is clear that there was no significant difference between Runs 4 and 10, Runs 5 and 9, and Runs 7 and 8. Runs 4 and 10 were conducted under similar conditions but Run 10 was 72 min longer, which indicated drying time had less impact on 6-gingerol reduction. There was a significant difference between Runs 4, 5 and 6, in which samples were dried at the same temperature but at different RH and with a different drying time. This showed that RH could have played a role in the decrease of 6-gingerol.

There was no significant difference between Runs 7 and 8. However, Run 8 had a lower average temperature and longer drying time. The reason for this result could be due to the combined impact of drying temperature and drying time.

Tab. 4 Characteristics of samples subjected to different treatments with changing conditions

Run	Drying conditions	Drying time (min)	6-gingerol content* (µg/mg)	CV (%)
4	60°C 10% RH to 50°C 20% RH	207	0.349	3.53
5	60°C 10% RH to 50°C 30% RH	133	0.578	4.79
6	60°C 20% RH to 50°C 40% RH	283	0.448	2.79
7	60°C 10% RH to 40°C 30% RH	253	0.401	2.47
8	60°C 10% RH to 30°C 40% RH	275	0.403	4.56
9	50°C 30% RH to 40°C 30% RH	231	0.588	4.40
10	50°C 20% RH to 60°C 10% RH	279	0.356	9.08
11	40°C 30% RH to 50°C 20% RH	282	0.497	0.98

*Average of three experiments

Tab. 6 shows ANOVA test results between constant drying conditions and changing drying conditions. Four groups showed no significant difference, which were Runs 1 and 4, Runs 1 and 10, Runs 2 and 6, and Runs 3 and 6. Runs 1 and 4 both obtained a lower gingerol yield while Run 4 was conducted at a higher temperature and lower humidity. The reason for this could be the much longer drying time of Run 1 (107 min longer). Similar situation happened in Runs 1 and 10, while Run 1 lasted 35 min longer than Run 10. Runs 2 and 6 had a similar drying time. However, Run 6 was conducted at a higher temperature and RH. This result again suggested that RH could affect 6-gingerol content in drying process.

Tab. 5 ANOVA test between changing drying conditions runs

Run	P value	Run	P value
4 vs 5	0.000	6 vs 8	0.000
4 vs 6	0.000	6 vs 9	0.000
4 vs 7	0.000	6 vs 10	0.000
4 vs 8	0.000	6 vs 11	0.000
4 vs 9	0.000	7 vs 8	0.863
4 vs 10	0.519	7 vs 9	0.000
4 vs 11	0.000	7 vs 10	0.000
5 vs 6	0.000	7 vs 11	0.000
5 vs 7	0.000	8 vs 9	0.000
5 vs 8	0.000	8 vs 10	0.000
5 vs 9	0.713	8 vs 11	0.000
5 vs 10	0.000	9 vs 10	0.000
5 vs 11	0.000	9 vs 11	0.000
6 to 7	0.0 00	10 vs 11	0.000

ANOVA, P=0.05

No significant difference between Runs 3 and 6 showed that drying at a higher temperature, shorter time and lower relative humidity results in a similar gingerol content as a run at lower temperature, longer drying time and higher humidity, which indicates that interactions between drying temperature, time and RH are likely to have an impact on 6-gingerol content.

Tab. 6 ANOVA test between constant and changing conditions.

Run	P value	Run	P value
1 vs 4	0.483	2 vs 8	0.006
1 vs 5	0.000	2 vs 9	0.000
1 vs 6	0.000	2 vs 10	0.000
1 to 7	0.001	2 vs 11	0.027
1 vs 8	0.001	3 vs 4	0.000
1 vs 9	0.000	3 vs 5	0.000
1 vs 10	0.301	3 vs 6	0.790
1 vs 11	0.000	3 vs 7	0.023
2 vs 4	0.000	3 vs 8	0.028
2 vs 5	0.000	3 vs 9	0.000
2 vs 6	0.662	3 vs 10	0.000
2 vs 7	0.005	3 vs 11	0.005

ANOVA, P=0.05

Predictive model for 6-gingerol

Drying time and drying temperature are considered as the two main factors affecting gingerol content (two-factors model). The prediction model function of 6-gingerol in this case is expressed by equation (1):

$$G = G_0 \exp(-k_{G_0} t) \qquad (1)$$

where G is the final 6-gingerol content, G_0 is the initial 6-gingerol content, k_{G_0} is the 6-gingerol rate constant and t is the drying time.

Combining equation (1) with the single term drying model for ginger we obtain equation (2):

$$G = G_0 \exp\left(-k_{G_0} \exp\left(\frac{h}{RT}\right) t\right) \qquad (2)$$

where h is the activation energy (J), R is the gas constant and T is the product absolute temperature (K).

Tab. 7 shows the experimentally determined value vs the model calculated 6-gingerol content for each of the drying treatments.

Tab. 7 Summary of 6-gingerol content from different drying treatments: experimental and model calculated values.

Run	Stage	Drying time (min)	6-gingerol content (µg/mg)	
			Experiment	Model
1		282	0.336	0.402
2		293	0.454	0.413
3		154	0.444	0.479
4	1	35		
	2	172	0.348	0.463
5	1	32		
	2	101	0.578	0.510
6	1	53		
	2	231	0.448	0.419
7	1	33		
	2	220	0.401	0.436
8	1	54		
	2	219	0.403	0.423
9	1	60		
	2	170	0.587	0.448
10	1	49		
	2	230	0.356	0.421
11	1	77		
	2	204	0.494	0.420

"-" means constant drying conditions. 1 and 2 means before changed drying conditions and after changed drying conditions.

The quality of the fit between the experimentally obtained values and the model calculated values was evaluated by the coefficient of determination (R^2) and root mean square error (RMSE). For the results shown in Tab. 7, they were R^2=0.4994 and RMSE= 0.0713.

The reasons for this relatively poor fit may have been due to the fact that there was a considerable level of variability in the initial moisture content of ginger rhizomes. Furthermore, the model did not take into account the RH of the drying air. In order to study the effects of RH, anew model (see equation (3)) was developed including RH:

$$G = G_0 \exp\left(-\left(k_{G_0} + A * RH\right) exp\left(\frac{h}{RT}\right) t\right) \qquad (3)$$

where A is a constant, RH is the relative humidity (decimal). Equation (3) is based on equation (2), and is the simplest modification to this model for including the effect of relative humidity on 6-gingerol depletion.

The new models showed an improvement of the fit having a higher coefficient of determination (R^2=0.5923) and a lower RMSE (0.0675).

4. Discussion

Combining a single term drying model and a three factors model for predicting gingerol content allows for devising the most appropriate drying conditions to obtain a maximum 6-gingerol yield.

A shorter drying time, a lower drying temperature and a higher RH reduce the 6-gingerol depletion in dried ginger.

The results suggest that the optimum drying condition of ginger is: air temperature of less than 40°C; RH of 40% at the late stage of drying, drying time not exceeding 300 min.

Acknowledgement

The authors of this study would like to acknowledge the contribution of Buderim Ginger Pty Ltd who supplied the ginger samples.

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Numerical modeling of the horizontal flow and concentration distribution of nitrogen within a stored-paddy bulk in a large warehouse

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DOI 10.5073/jka.2018.463.087

Abstract

The insect population in grain stores can be kept under control by maintaining a high concentration of N_2 gas throughout the grain bed. The development of controlled atmosphere storage technology for insect control requires an accurate prediction of the distribution of introduced gases in bulk grain. In this paper, based on the convective-diffusion model, the horizontal flow of N_2, which was introduced into the paddy bulk in a large warehouse by means of the horizontal ventilation system, are modeled as fluid flow in a porous medium. The experimental data for N_2 transfer and flow through ducts and bulk paddy were used to validate the model. The equations were solved using the finite difference method, and the predictions from the proposed model were in good agreement with the experimental results. The concentration distribution and flow uniformity of nitrogen in stored paddy were also analyzed during the nitrogen-filling procedure for CA storage. It was shown that it is feasible and practical to introduce nitrogen into stored bulk grain in a large warehouse by means of the horizontal ventilation system.

Keywords: numerical modeling, stored paddy, concentration distribution, nitrogen-filling procedure

1. Introduction

Chemical control methods such as fumigation with phosphine are effective against insect pests, but have disadvantages including residue problems and development of tolerance by insects (Banks et al.,1990). In the recent past, the use of controlled atmosphere (CA) as a safe residue-free alternative to chemical fumigants and protectants has gained popularity for controlling insects infesting stored grain. Controlled atmosphere with low oxygen (O_2) and high nitrogen (N_2) in storage by injecting nitrogen into the storage displacing the oxygen is just one of a number of methods that can be used for controlling pests in stored products.

Controlled atmosphere storage for insect control involves the alteration of the proportion of the normal atmospheric gases, i.e., N_2, carbon dioxide (CO_2) and O_2, to create an atmosphere that is lethal to the insects. The success of CA and fumigants in killing stored product pests depends on the movement of gas through and uniform distribution of the gas in the stored grain, and maintaining a lethal gas concentration level for the required exposure period.

Three-dimensional heat, mass and momentum transfer models with concentration species were developed by Singh et al. (1993), Lawrence et al. (2013a, 2013b) and Mat Isa et al. (2014) for predicting fumigant concentrations in a rectangular domain or cylindrical silo. These models need to be validated under a wider range of conditions, and can then be used to evaluate causes of fumigation failures and to develop best management practices to prevent the failures. Although