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Spray-drying of ginger juice and physicochemical properties of ginger powders

Singhanat Phoungchandang, Anong Sertwasana

Department of Food Technology, Khonkaen University, Mittapab Road, Muang District, Khonkaen 40002, Thailand

*Corresponding author, e-mail: sinpho@kku.ac.th

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ABSTRACT: The maturity of ginger rhizomes was studied by measuring their moisture content, fibre, density, and 6-gingerol content. Ginger rhizomes were harvested and divided into three groups according to their age of 4–6, 7–9, and 10–12 months. The results revealed that as ginger rhizomes age, moisture content and density decreased, while fibre and 6-gingerol content increased. Therefore, ginger maturity with the age of 10–12 months was used in the drying process. The effects of the drying aids maltodextrin and liquid glucose and inlet air temperatures on the properties of ginger powders were assessed. Moisture content, water activity, bulk density, water adsorption index, 6-gingerol content, and colour values of ginger powders decreased with increasing inlet air temperatures. Particle size, solubility, and water solubility index increased with increasing inlet air temperatures ($p \leqslant 0.05$). Moisture content, water activity, water adsorption index, and particle size decreased with increasing the drying aids. Solubility, water solubility index, and yield increased with increasing the drying aids. The addition of 5% liquid glucose and an inlet air temperature of 120 °C resulted in good properties and the highest 6-gingerol content of the ginger powders. It was noted that liquid glucose could function as a drying aid and as an encapsulating agent.

KEYWORDS: 6-gingerol, liquid glucose, maltodextrin

INTRODUCTION

Ginger rhizome processing is difficult and requires imaginative new methods to give high yields with minimum cost to the village level processors. The total export of ginger rhizomes from Thailand in 2002/2003 was 26 908 tonnes. Excess production of ginger from growing areas causes problems in moving this volume of raw product to the market and processing plants. Ginger rhizomes contain about 82.6% moisture. Ginger rhizomes contain phytochemical substances such as (n)-gingerol, zingerone, and (n)-shogaol[1] which function as an antioxidant and anticancer agent[2]. Drying is the process of removing the moisture from a food product which is accomplished by heating. In this process, two transport phenomena occur simultaneously: moisture movement and heat transfer. Spray drying of most fruit and vegetable juices require drying aids to accomplish the drying process. Attiyat[3] produced a free flow and good quality tomato powder using an industrial spray dryer. Maltini et al[4] produced peach, pear, and apricot powders using vacuum belt and freeze drying. Bahandari et al[5] studied the conditions for producing blackcurrant, raspberry, and apricot powders with two laboratory spray dryers using maltodextrin with DE 6, 12, 19 as drying aids and obtained the ratio of additive materials. Gupta[6] produced free flow orange juice powders using liquid glucose as a drying aid. He used many spray dryers with different atomizing systems and found that a powder flow film was formed when the inlet air temperature was higher than the sticky point. Cárcamo[7] studied the technical feasibility of spray drying apple juice. Chegini and Ghobadian[8] found that spray drying of orange juice without any drying aid could not produce dry orange juice powder and maltodextrin increased drying yield of 18–35%.

The objectives of this work were to investigate the maturity of ginger rhizomes. The effects of inlet air temperatures and drying aids on moisture content, water activity, particle size, bulk density, solubility, water solubility index, water absorption index, 6-gingerol content, and colour values of ginger powders were also determined.

MATERIALS AND METHODS

Maturity

Ginger rhizomes (*Zingiber officinale* Roscoe) were harvested from Petchaboon province, Thailand. The ginger rhizomes were divided into 3 groups according to their age of 4–6, 7–9, and 10–12 months. Moisture content[9], fibre[9], density[10], and 6-gingerol content[11] were determined. A completely randomized design was used to study the factors affecting ginger rhizome maturity. Two replications were used to determine the main factors. SPSS version 16 for Windows was used to do ANOVA.

Spray drying

Ginger rhizomes (10–12 months) were cleaned in 5 ppm chlorinated water and cut into small pieces. Ginger juice was extracted using a heavy duty hydraulic press (Samson). The spray drying experiments were performed using a pilot plant spray dryer (PML-20, Pamalyne). The feed rate of the spray dryer was 14–18 ml/min by a peristaltic pump and the ginger juice was subjected to a rotary atomizer at 35 000g. An electric heater heated the inlet air to a temperature of 120–150 °C. The outlet air temperature was 75–85 °C. Maltodextrin and liquid glucose were used as drying aids at the concentration of 0, 5, and, 10%. The drying aids and their proportion with ginger juice were chosen based on previous investigations. Drying aids should reduce hygroscopic and thermoplastic properties with variation of the ginger juice properties and should not alter the quality of the ginger powders. The pilot plant spray dryer was situated in a food processing pilot plant with a stable environment. The ambient air temperature was 30.5 °C and the relative humidity was 71.5 ± 1.9%. Before starting the experiments, the atmospheric temperature was measured with a data logger (DT 800, Data Taker, Scoresby) and the relative humidity was measured with a thermohygrometer (HD9216, DELTA OHM-VIAG Co., Galilei). In all experiments, atomizer speed and air pressure were constant at 35 000g and 3.0 kPa, respectively. A completely randomized $2 \times 3 \times 3$ factorial experiment was used to study the main factors affecting the drying process, namely, drying aids (maltodextrin, MD and liquid glucose, LG at the concentration of 0, 5, and 10% by weight) and inlet air temperature (120, 135, and 150 °C) and interaction between the main factors. Duncan's multiple range was used to determine the significant treatments at 95% confidence interval.

QUALITY ANALYSIS

Moisture content

Moisture content was determined by the AOAC method[9]. Mass loss after 5 g of each powder was placed in an oven dryer at 105 °C (U30, Memmert) for 3 h was determined.

Water activity (a_{w})

Ginger powders of 0.5 g were determined using a water activity meter (AQUALAB series 3TE, Device Co., Germany) at 25 °C.

Colour

The colour of ginger powder was measured using Hunter Lab (ULTRASCAN XE U3115, Color Global Co.) and expressed as L^*, a^*, and b^* values.

Water solubility index (WSI) and water absorption index (WAI)

Water solubility index and water absorption index were determined using the method described in Ref. 12. A small sample of dry powders (2.5 g) was added to 30 ml of water at 30 °C in a 50 ml centrifuge tube, stirred intermittently for 30 min, and then centrifuged for 10 min at (5100g). The supernatant was carefully poured off into a Petri dish and oven-dried overnight. The amount of solid in the dried supernatant as a percentage of the total dry solids in original 2.5 g sample gave an indication of the WSI. Wet solid remaining after centrifugation was dried in an oven overnight. WAI was calculated as the weight of dry solid divided by the amount of dry sample.

Solubility

Solubility was determined using a modified version of the method of Al-Kahtani and Bakri[13]. A small sample of dry powders of 0.6 g was added to 400 ml of water at 70 °C in a 50 ml beaker. The mixture was stirred using a magnetic stirrer at 7 rpm. Solubility was measured as the time taken to dissolve the dry powders completely.

Bulk density

Bulk density was determined by adding 20 g of ginger powder to a 50 ml graduated cylinder and holding the cylinder on a vibrator for 1 min. The bulk density was calculated by dividing mass of the powders by the volume occupied in the cylinder[14].

Particle size

Particle size of ginger powders was determined using the method described by Farral[15]. A sample of dry ginger powder (100 g) was used. A suitable sieve shaker (Retsch, Serial No. 52109013, GmbH 8 Co. KG) and designated sizes of 30, 40, 50, 70, 100, 140, 200, and 300 mesh and a balance of accuracy ± 0.01 g were used. The sample was placed on the top sieve of the shaker and it was operated until the weight of ginger powders on the finest sieve reached equilibrium, as determined by inspection and weighing at 5 min intervals after an initial sieving time of 10 min. The analysis of weight distribution data was based on the assumption that the distributions were lognormal. The size of particle was reported in terms of geometric mean diameter (d_{gw}) and geometric standard deviation (S_{gw}) by weight. We used

$$\begin{aligned} d_{\mathrm{gw}} &= d_{50} = \text{particle diameter at 50\% probability} \\ &= \text{particle size at 84\% probability}/d_{\mathrm{gw}} \\ &= d_{\mathrm{gw}}/\text{particle diameter at 16\% probability} \end{aligned}$$

Determination of 6-gingerol content

6-Gingerol of ginger powders was determined using a method modified from Balladin et al[11]. A sample of dry powders (1 g) was extracted in 10 ml methanol overnight, and then centrifuged for 10 min at 5100g. The supernatant was filtered through Whatman paper No. 2 and then the filtrate was filtered through a 0.45 µm nylon filter. Reversed-phase high performance liquid chromatography (HPLC) was used for the determination of 6-gingerol in the extract of ginger rhizomes and ginger powders. 20 µl of the extract was injected into the HPLC. The water HPLC system was used. The column was a reversed-phase HI5C$_{18}$ (150 mm × 4.6 mm), id 5 µm (HiChrom) with Nova-Pak C$_{18}$ pre-column (Water Co.). The mobile phase was methanol:double deionized water (70:30 v/v). The solvent flow rate was 1.2 ml/min. The UV detector (Water 480) was set at 282 nm.

RESULTS AND DISCUSSION

Maturity

The moisture content and density of ginger rhizomes decreased with the increasing fibre and 6-gingerol content ($p \leqslant 0.05$, Table 1). The fibre content[16] and an active ingredient (6-gingerol)[11] increased with age. Baranowski[17] reported that 6-gingerol in ginger increased with the age of plant from 12 to 34 weeks and found that the mature ginger that was 34 weeks old contained the highest 6-gingerol content. In this work, the mature ginger aged 10–12 months (40–48 weeks) contained the largest amount of 6-gingerol instead. Therefore, 10–12 month-old ginger was used in the spray drying process.

Moisture content and water activity

Inlet air temperature and drying aids reduced the moisture content and a_{w} of the ginger powders to less than 1.70%, which is desirable for the spray drying process (Table 2). Inlet air temperatures and drying aids had an effect on moisture content and a_{w} of the finished ginger powders ($p \leqslant 0.05$). High inlet drying air temperature often resulted in decreasing moisture content and a_{w}. Generally, the greater the temperature difference between the particles, the greater the evaporation rate[18]. Similar results have been reported for spray dried tomato paste[14], pineapple juice[19], and sweet potato puree[8]. Moisture content also decreased with increasing maltodextrin concentration as a drying aid. This was due to the hygroscopic property of maltodextrin and hence its reduced moisture content and a_{w}.

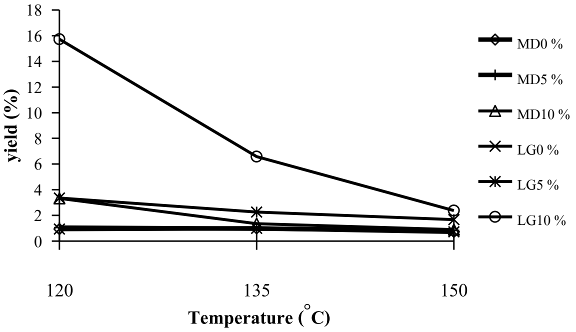

Fig. 1 The effect of inlet air temperatures and drying aids on yield.

Particle size and bulk density

Spray drying experiments were performed. Maltodextrin (MD) and liquid glucose (LG) were used and functioned as drying aids. With these drying aids, the yield increased (Fig. 1). Results indicated that yield was increased to 15.7% with liquid glucose concentration of 10% at 120 °C. The bulk density decreased with increasing inlet air temperature (Fig. 2). The bulk density of ginger powders was in the range 480–830 kg/m^3. Particle size of ginger powders increased with inlet air temperatures but decreased with increased concentration of maltodextrin and liquid glucose (Fig. 3). The particle size of ginger powder was in the range 47 to 84 µm. This increment often resulted in a rapid formation of a dried layer at the droplet surface and the particle size was due to skinning over and case-hardening of the droplets at the higher temperatures. This leads to the formation of vapour-impermeable film droplet surfaces, followed by the formation of vapour bubbles and droplets[8].

Solubility, WSI and WAI

The instant properties of a powder involve the ability of a powder to dissolve in water. Most powdered foods are intended for rehydration. Hence the ideal

Table 1 Maturity of ginger rhizomes.

Parameter	Age of ginger rhizomes		
	4–6 months	7–9 months	10–12 months
Moisture content (%)	93.37 ± 0.75^{a}	90.34 ± 1.14^{b}	82.64 ± 4.81^{c}
Fiber (% dry basis)	10.04 ± 0.72^{c}	10.82 ± 0.38^{b}	11.72 ± 0.49^{a}
Density (kg/m^3)	1024.02 ± 2.35^{a}	999.87 ± 6.92^{b}	986.55 ± 0.93^{c}
6-gingerol (mg/1000 g dry basis)	1015.10 ± 137.60^{c}	1682.20 ± 81.74^{b}	2337.10 ± 80.75^{a}

Differing superscripts indicate significant differences ($p \leqslant 0.05$).

Table 2 Moisture content, water activity, water solubility index and water absorption index of spray-dried ginger powders.

Drying aid	Concentration (%)	Inlet air temperature (°C)	Moisture (%)	a_w	WSI (%)	WAI
MD	0	120	15.36 ± 0.01^{a}	0.43 ± 0.00^{a}	20.29 ± 0.33^{i}	5.041 ± 0.02^{a}
MD	0	135	9.37 ± 0.01^{b}	0.33 ± 0.00^{f}	57.83 ± 0.84^{g}	1.929 ± 0.01^{c}
MD	0	150	7.78 ± 0.01^{d}	0.31 ± 0.00^{h}	88.55 ± 1.03^{f}	1.538 ± 0.00^{de}
MD	5	120	4.80 ± 0.00^{g}	0.40 ± 0.00^{b}	35.06 ± 1.66^{h}	2.945 ± 0.02^{b}
MD	5	135	3.81 ± 0.00^{j}	0.39 ± 0.00^{c}	88.15 ± 0.44^{f}	1.547 ± 0.00^{d}
MD	5	150	3.42 ± 0.00^{k}	0.28 ± 0.00^{k}	91.84 ± 1.32^{c}	1.528 ± 0.00^{def}
MD	10	120	2.40 ± 0.00^{l}	0.37 ± 0.00^{d}	87.71 ± 1.37^{f}	1.540 ± 0.00^{de}
MD	10	135	1.67 ± 0.03^{n}	0.31 ± 0.00^{i}	91.50 ± 0.45^{cd}	1.516 ± 0.00^{ef}
MD	10	150	0.74 ± 0.00^{o}	0.25 ± 0.01^{n}	93.82 ± 0.81^{b}	1.510 ± 0.00^{f}
LG	0	120	15.36 ± 0.01^{a}	0.43 ± 0.00^{a}	20.29 ± 0.33^{i}	5.041 ± 0.02^{a}
LG	0	135	9.37 ± 0.01^{b}	0.33 ± 0.00^{f}	57.83 ± 0.84^{g}	1.929 ± 0.01^{c}
LG	0	150	7.78 ± 0.01^{d}	0.31 ± 0.00^{h}	88.55 ± 1.03^{f}	1.538 ± 0.00^{de}
LG	5	120	5.60 ± 0.05^{e}	0.32 ± 0.00^{g}	87.92 ± 0.88^{f}	1.541 ± 0.00^{de}
LG	5	135	5.25 ± 0.04^{f}	0.29 ± 0.00^{j}	90.66 ± 1.14^{de}	1.518 ± 0.00^{ef}
LG	5	150	4.56 ± 0.00^{h}	0.25 ± 0.00^{n}	93.90 ± 0.73^{b}	1.516 ± 0.00^{ef}
LG	10	120	8.48 ± 0.00^{c}	0.34 ± 0.00^{e}	89.83 ± 1.15^{e}	1.516 ± 0.00^{ef}
LG	10	135	4.44 ± 0.01^{i}	0.28 ± 0.00^{l}	93.39 ± 0.48^{b}	1.515 ± 0.00^{ef}
LG	10	150	1.84 ± 0.01^{m}	0.27 ± 0.00^{m}	96.01 ± 0.43^{a}	1.507 ± 0.00^{f}

Differing superscripts indicate significant differences ($p \leqslant 0.05$).

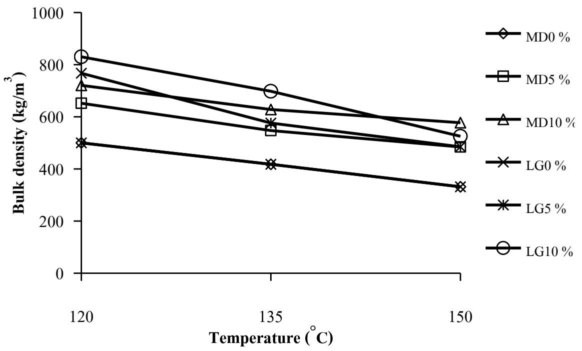

Fig. 2 The effect of inlet air temperatures and drying aids on bulk density.

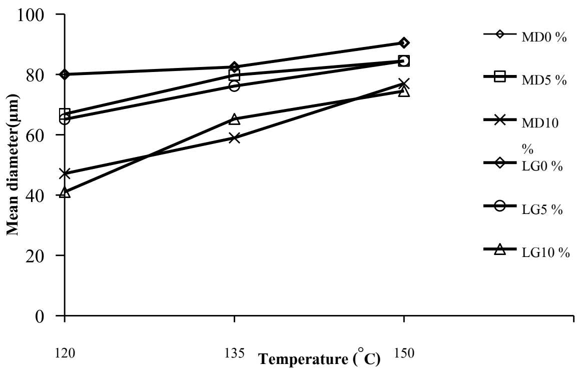

Fig. 3 The effect of inlet air temperatures and drying aids on mean diameter.

powder would wet quickly and thoroughly, sink rather than float and disperse/dissolve without lumps[20]. The addition of maltodextrin and liquid glucose during spraying of ginger juice affected the solubility of ginger powder. Water solubility index increased with increasing maltodextrin and liquid glucose up to 96% (Table 2). Conversely, adding drying aids reduced the

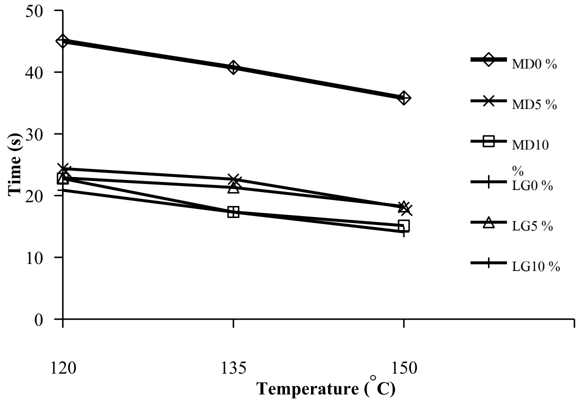

Fig. 4 The effect of inlet air temperatures and drying aids on solubility.

water-holding capacity of the ginger powders (Fig. 4 and Table 2). These effects of the drying aids could be attributed to the inverse relationship between the drying aids concentration and the mean particle size (Fig. 3). The drying aids could form an outer layer on the drops and alter the surface stickiness of particles due to the transformation into a glassy state[21]. The changes in surface stickiness reduce the particle-particle cohesion resulting in less agglomeration, and therefore, lower water-holding capacity of the powders[18].

6-Gingerol content

The HPLC results revealed that the drying aids retained more 6-gingerol than without the drying aids (Table 3). Many researchers found that maltodextrin could decrease diffusion coefficients for dilute volatile organic substances. As a consequence, a major goal in the design of concentration and drying processes was to establish conditions that lead rapidly to a high concentration of major solutes at the surface thereby sealing or encapsulating the surface against further volatiles loss[22,23]. The highest 6-gingerol remaining was found with 5% liquid glucose. It was interesting to note that liquid glucose could function as drying aid and as an encapsulating agent.

Colour values

Colour was represented by L^* and a^*/b^* where L^* values range from black (0) to white (100). The a^*/b^* ratio described yellowness of ginger powder products[24]. As the inlet air temperatures were increased, the L^* value and yellowness of ginger powders decreased (Table 3). In general, higher drying air temperature affects colour of dried product due to a non-enzymatic browning reaction[25]. Maltodextrin and liquid glucose were able to preserve yellowness of the ginger powder products. The best colour value of ginger powder products were achieved at 120 °C inlet temperature and 5% liquid glucose.

Table 3 Lightness, a^*/b^* value, and 6-gingerol content of spray-dried ginger powders.

Drying aid	Concentration (%)	Inlet air temperature (°C)	L^*	a^*/b^*	6-gingerol (mg/1000 g sample)
MD	0	120	60.30 ± 1.12^{i}	0.16 ± 0.01^{g}	109.99 ± 0.27^{h}
MD	0	135	57.92 ± 0.20^{j}	0.35 ± 0.01^{c}	62.90 ± 3.45^{hi}
MD	0	150	52.23 ± 0.57^{k}	0.51 ± 0.00^{a}	25.71 ± 3.17^{i}
MD	5	120	70.50 ± 0.17^{f}	0.04 ± 0.00^{j}	627.02 ± 12.33^{bc}
MD	5	135	72.35 ± 0.24^{e}	0.13 ± 0.00^{h}	620.05 ± 14.51^{bc}
MD	5	150	68.19 ± 0.75^{g}	0.43 ± 0.00^{b}	571.95 ± 33.62^{cd}
MD	10	120	78.86 ± 0.47^{b}	0.09 ± 0.00^{i}	427.45 ± 3.50^{e}
MD	10	135	80.69 ± 0.31^{a}	0.11 ± 0.01^{i}	382.69 ± 6.77^{e}
MD	10	150	79.28 ± 1.02^{b}	0.16 ± 0.00^{g}	315.14 ± 1.42^{f}
LG	0	120	60.30 ± 1.12^{i}	0.16 ± 0.01^{g}	109.99 ± 0.27^{h}
LG	0	135	57.92 ± 0.20^{j}	0.35 ± 0.01^{c}	62.90 ± 3.45^{hi}
LG	0	150	52.24 ± 0.55^{k}	0.51 ± 0.00^{a}	25.71 ± 3.17^{i}
LG	5	120	75.69 ± 1.42^{c}	0.19 ± 0.01^{f}	1029.72 ± 50.44^{a}
LG	5	135	72.42 ± 0.28^{e}	0.18 ± 0.00^{f}	659.81 ± 46.83^{b}
LG	5	150	72.27 ± 0.14^{e}	0.21 ± 0.00^{e}	394.95 ± 23.91^{e}
LG	10	120	73.84 ± 0.15^{d}	0.11 ± 0.00^{i}	623.35 ± 87.96^{bc}
LG	10	135	70.13 ± 0.05^{f}	0.21 ± 0.00^{e}	523.20 ± 3.45^{d}
LG	10	150	66.15 ± 0.25^{h}	0.26 ± 0.00^{d}	252.31 ± 7.84^{g}

Differing superscripts indicate significant differences ($p \leqslant 0.05$).

CONCLUSIONS

The inlet air temperatures and drying aids affected the quality of dried ginger powders. Liquid glucose as a drying aid increased the drying yield to 15.7%. Moisture content, a_{w}, bulk density, water adsorption index, 6-gingerol and colour value of ginger powders decreased with increasing inlet air temperature. Particle size, solubility and water solubility index increased with increasing inlet air temperatures. Water solubility index and yield increased with increasing drying aids concentration. The best quality ginger products were achieved at 120 °C inlet temperature and 5% liquid glucose.

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