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Effect of vacuum infrared drying and tray drying on physicochemical properties, antioxidant activities, and α-amylase and α-glucosidase inhibition of banana bract powder

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Abstract

Banana bracts, a by-product of banana production, were subjected to vacuum infrared and tray drying at 50, 60, and 70°C, and the physicochemical properties, antioxidant activity, and digestive enzyme inhibition of banana bract powder were investigated. Banana bract powder contained 15.27 - 15.75% crude fibre. The yellowness, browning index, and water absorption of banana bract powder dried by a vacuum infrared dryer was higher than tray-dried powder. Bulk density and tapped density of banana bract powder dried by a vacuum infrared dryer were significantly lower, while the Carr index was higher than the tray-dried sample. Total phenolic content (TPC) and DPPH of powder dried by tray and vacuum infrared dryers decreased with increasing drying temperature. Vacuum infrared powder dried at 70°C effectively enhanced the uptake of glucose, and inhibited α-glucosidase activity compared to tray-dried powder, while tray drying at 60°C gave the highest α-amylase inhibition. The results indicated that banana bract powder could be added as a functional ingredient in food products.

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Introduction

Banana flower is a by-product of banana harvesting. Banana flower consists of bracts and male flowers. Banana bracts are modified leaves that grow close to flower clusters. The inner bracts of the banana flower are used as food ingredients in soup and deep-fried products. Banana bracts are rich in fibre and antioxidants, including phenolics and anthocyanins. The inner bracts contain crude fibre (10.73%), dietary fibre (66.22%), and 9.44 mg polyphenol/g dry sample (Begum and Deka, 2019a). The abundant free phenolics found in the inner bracts include quinic acid, while the bound phenolic comprises ferulic acid. Banana bracts contain dietary fibre that helps to control blood glucose and insulin levels, decrease blood cholesterol levels, and reduce the risk of colon cancer (Begum and Deka, 2019b). Hyperglycaemia is one factor contributing to the development of diabetes mellitus. Digesting carbohydrates by glycoside hydrolases including α-amylase and α-glucosidase leads to an increase in blood glucose levels. Inhibition of α-amylase and α-glucosidase in the digestive system decreases the hydrolysis of starch, resulting in lower blood glucose levels that effectively control diabetes (Ramu *et al.*, 2014). Phytosterols isolated from banana flower, such as 31-norcyclolaudenone, showed inhibition against α-amylase and α-glucosidase (Sheng *et al.*, 2017). Plantain inflorescence is a rich source of phytochemicals and dietary fibre, which decreases postprandial hyperglycaemia by inhibiting digestive enzymes, and increasing glucose uptake in L6 myoblasts (Arun *et al.*, 2017).

Drying process removes water from food products. Typical drying methods include tray, freeze, vacuum, and microwave drying. Conventional drying process has some disadvantages such as long drying time, low energy efficiency, and degradation of phytochemical compounds and vitamins, while novel drying techniques improve the drying characteristics of food products with low energy consumption and short drying time (Bozkir *et al.*, 2020). Vacuum microwave drying and vacuum

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infrared drying are alternative methods for drying fruit and vegetable products. Infrared drying transfers infrared radiation energy from the heating element to the product surface. This energy is then absorbed by the sample, and converted into heat. Infrared vacuum drying operates at low pressure and temperature, and reduces the oxidation of the material, resulting in improved product qualities. Vacuum infrared drying (VID) has high energy efficiency and drying rate, while the low drying time improves the rehydration abilities of dried products. VID has been applied in drying bananas, oranges, kiwifruits, orange peels, button mushrooms, Cistanche, pumpkins, and pears. The process parameters including vacuum pressure, temperature, and thickness affect product quality. Cistanche slices dried by VID at optimal temperature of 55°C created a porous structure, which retained bioactive components and antioxidant activity (Jiang *et al.*, 2022). Swasdisevi *et al.* (2007) reported that the optimal conditions for producing banana slices dried using an infrared dryer were temperature of 50°C, pressure of 5 kPa, and thickness of 2 mm. Bozkir *et al.* (2020) stated that vacuum infrared drying retained volatile compounds of orange peel compared to tray drying, while drying techniques for banana bracts have been reported as thin layer, tray, and microwave drying. Jha *et al.* (2021b) dried banana blossom using microwave drying at different power levels, while Jha *et al.* (2021a) studied the effect of pre-treatment on the properties of banana flower powder.

Vacuum infrared drying can achieve high quality products through rapid energy transfer at low drying temperatures. However, limited information exists on vacuum infrared drying of banana bract powder, and effect of vacuum infrared drying process on product characteristics. Therefore, the objectives of the present work were to compare the physicochemical properties, antioxidant activity, and digestive enzyme inhibition of banana bract powder dried by vacuum infrared drying and tray drying techniques.

Materials and methods

Materials

Banana blossom was obtained from a local farm in Phitsanulok Province, Thailand. Porcine pancreatic α-amylase from *Aspergillus oryzae*, and α-glucosidase from *Saccharomyces cerevisiae* were purchased from Sigma-Aldrich Chemicals (St. Louis, MO, USA). GOPOD reagent was purchased from Megazyme (Bray, Wicklow, Ireland), while glucose was purchased from HiMedia (Maharashtra, Mumbai, India). *p*-Nitrophenyl-α-D-glucopyranoside (*p*NPG), 1,1-diphenyl-2-picrylhydrazyl (DPPH), and 2,4,6- Tris (2-pyridyl)-s-triazine (TPTZ) were purchased from Sigma-Aldrich Chemicals (St. Louis, MO, USA). Iron (III) chloride hexahydrate ($FeCl_3.6H_2O$) was purchased from PanReac Applichem (Castellar del Vallès, Barcelona, Spain), and Folin-Ciocalteu's phenol reagent was purchased from LOBA Chemie (Colaba, Mumbai, India). All reagents used were of analytical grade.

Dried banana bract preparation

The fresh banana blossom was washed with water, and five to six outer bracts were peeled off. The whitish inner bracts were then removed, cleaned with water, sliced at 3 mm width, soaked in 0.5% sodium metabisulphite and 0.1% citric acid solution for 30 min, and drained for 10 min. The sliced samples were dried using a tray dryer at 50, 60, and 70°C and a vacuum infrared dryer with 0.8 bar pressure and 1,700 watts at 50, 60, and 70°C. The dried banana bract slices were then milled using a stainless-steel grinder (DXM-200, DXFLL, China), passed through a 50-mesh sieve, packed in aluminium foil bags, and stored at 5°C for further analysis.

Chemical composition

The moisture, protein, lipid, fibre, and ash contents of fresh banana bracts were determined following the AOAC (2005) method. Similarly, the moisture and fibre contents of banana bract powder were also determined following the AOAC (2005) method.

Colour measurement

The colour of fresh banana bract and the powder was determined using a colorimeter (Colour Reader CR-20, Konica Minolta, Japan). The L^*, a^*, and b^* values were recorded. The browning index (BI) was calculated according to Lee *et al.* (2022) using Eq. 1:

$$\text{Browning index} = 100(X-0.31)/0.172 \quad \text{(Eq. 1)}$$

where, $X = (a^* + 1.75L^*) / (5.645L^* + a^* - 3.012b^*)$.

The yellowness index (YI) was calculated based on Varela *et al.* (2022) using Eq. 2:

Yellowness = 142.86 b^*/L^* (Eq. 2)

Bulk density, tapped density, and Carr index (CI)

The bulk density and tapped density of dried banana bracts were measured according to Jha *et al.* (2021a). Briefly, 1 g of powder was added to a 10 mL cylinder, and the volume occupied was measured. The bulk density of the powder was calculated from the mass divided by the volume. The powder was then tapped manually, and the tapped density was calculated as the mass of compact powder divided by the volume after tapping. The flowability of the powder was determined as the Carr index (CI) following Raja *et al.* (2019), with the CI calculated from the bulk and tapped powder densities using Eq. 3:

CI = [(tapped density – bulk density) / tapped density] × 100 (Eq. 3)

Swelling power and solubility

The swelling power and solubility were determined according to Jha *et al.* (2021a) with some modifications. Briefly, samples of 0.1 g were dispersed in 10 mL of distilled water, and the suspensions were heated to 80°C in a water bath for 30 min. The cooked paste samples were centrifuged at 10,000 rpm for 10 min, and the supernatants were placed in pre-weighed aluminium cans before drying at 105°C to constant weight to determine sample solubility. After decanting the supernatant, the residue weight was recorded to determine the swelling power.

Oil absorption capacity

The oil absorption capacity was measured according to Jha *et al.* (2021a). Briefly, a weight of 0.1 g of sample was mixed with 10 mL of oil in a 50 mL centrifuge tube. The mixture was stirred using a shaker for 60 min, followed by centrifugation at 10,000 rpm for 15 min. The oil absorption capacity was measured in grams of oil absorbed by one gram of the sample.

Water absorption capacity

The water absorption capacity was measured according to Jha *et al.* (2021a). Briefly, a weight of 0.1 g of sample was mixed with 10 mL water in a 50 mL centrifuge tube. The mixture was stirred with a shaker for 60 min, and centrifuged at 10,000 rpm for 15 min. The separated water and weight were recorded. The water absorption capacity was measured in terms of grams of water absorbed by one gram of the sample.

Antidiabetic assays

Glucose adsorption capacity

Glucose adsorption capacity was measured according to Ou *et al.* (2001). Briefly, a sample (0.1 g) was added with 10 mL of 1 mM glucose. The mixture was stirred, held in a water bath at 37°C for 6 h, and then centrifuged at 6,000 rpm for 10 min. The glucose content in the supernatant was determined using a D-glucose assay kit (Megazyme, Bray, Ireland), with absorbance measured by a spectrophotometer at 510 nm. The difference in concentration of the control and the supernatant was the concentration of glucose absorbed by the sample.

α-Amylase and α-glucosidase inhibition

Sample preparation was prepared according to Chiang *et al.* (2021) with minor modifications. Briefly, dried banana blossom (0.5 g) was extracted with 100 mL of 80% ethanol at room temperature for 24 h, and the extracts were concentrated using a rotary evaporator (Hei-aVap Core, Heidolph, Germany). The extracts were stored at -20°C for α-amylase inhibition and α-glucosidase inhibition analyses.

The α-amylase inhibition test was determined according to Arun *et al.* (2017) and Bashary and Khatik (2019). Briefly, a volume of 100 µL of the extracts was added to 100 µL of α-amylase (0.4 U/mL) in phosphate buffer pH 6.9, and incubated at 37°C for 10 min. The sample was then mixed with 1% soluble starch, and incubated for 15 min at room temperature before adding 0.1 M hydrochloric acid (800 µL) to stop the reaction followed by 100 µL of iodine solution (5 mM I_2 and 5 mM KI). The absorbance was measured using a spectrophotometer at 630 nm. The percentage of α-amylase inhibition was then calculated using Eq. 4:

Percentage of α-amylase inhibition = 100 - ((absorbance of control - absorbance of sample) / absorbance of control) × 100%) (Eq. 4)

where, absorbance of control = absorbance of negative control (no α-amylase, 0% enzyme activity) - absorbance of positive control (no inhibitor, 100% enzyme activity).

α-Glucosidase inhibition activity was determined following the method of Ramu *et al.* (2014). Briefly, a 700 µL aliquot of phosphate buffer (50 mM, pH 6.8) and 100 µL of extract were mixed before addition of 100 µL of α-glucosidase (0.4 U/mL). The mixture was pre-incubated for 10 min at 37°C. After incubation, 100 µL of 0.5 mM *p*NPG solution in 50 mM phosphate buffer (pH 6.8) was added, and the reaction was maintained at 37°C for 20 min before termination by adding 250 µL of 0.1 M Na_2CO_3. Enzyme activity was determined by measuring the absorbance of the liberated *p*-nitrophenol from *p*NPG at 405 nm. The absorbance was compared with the control that contained buffer without a test sample. Results were expressed as α-glucosidase inhibition using Eq. 5:

Percentage of α-glucosidase inhibition = (absorbance of control - absorbance of sample) / absorbance of control) × 100% (Eq. 5)

Total phenolic content and antioxidant activity

Bioactive compound extraction of the fresh sample and dried banana bract powder followed the method described by Falleh *et al.* (2012) and Thaweesang (2019) with some modifications. Briefly, a 1.50 g sample was mixed with 15 mL of ethanol (80%) in a 50 mL plastic centrifuge tube, and then placed in an ultrasonic bath (Elmasonic S30H, Elma, Germany) filled with cold water for 30 min with gentle shaking every 5 min. The extract solution was then centrifuged at 6,000 rpm for 10 min, and filtered through Whatman no. 4 filter paper. The extract was stored at 0°C for further analysis.

The TPC was determined by the Folin-Ciocalteu colorimetric method with minor modifications (Shao *et al.*, 2014). Briefly, a volume of 300 µL of diluted extracts or standard solutions was added to 1.5 mL of 10-fold diluted Folin-Ciocalteu reagent, and neutralised with 1.2 mL saturated sodium carbonate (7.5%, w/v). Absorbance was measured at 765 nm (Genesys20, Thermo, USA), with the result expressed as mg of gallic acid equivalent per 100 g of sample (dry weight).

The DPPH assay was performed according to Shao *et al.* (2014) with minor modifications. Briefly, a 0.1 mM of DPPH radical solution was prepared in 80% ethanol. The diluted extracts or standards (500 µL) were added to 1 mL of DPPH solution. After incubating for 30 min in the dark, the absorbance was measured using a spectrophotometer at 517 nm, with the result expressed as mg of Trolox equivalent per 100 g of sample (dry weight).

The Ferric-reducing antioxidant power (FRAP) assay was determined according to Thuengtung *et al.* (2018). Briefly, a sample volume of 50 µL was mixed with 1.5 mL of FRAP reagent containing 300 mM acetate buffer (pH 3.6), 10 mM TPTZ in 40 mM HCl, and 20 mM $FeCl_3$ (10:1:1, v/v/v). The mixture was incubated at 37°C for 30 min and the absorbance was measured at 595 nm, with the result expressed as mg of Trolox equivalent per 100 g of sample (dry weight).

Statistical analysis

Analysis of variance (ANOVA) was performed using statistical software (Version 17.0, SPSS Inc., USA). Differences among means were compared using the least significant difference ($\alpha = 0.05$).

Result and discussion

Drying times of the banana bract samples using a tray dryer at 50, 60, and 70°C were 210, 180, and 120 min, respectively, while drying times for the vacuum infrared dryer at 50, 60, and 70°C were 210, 120, and 80 min, respectively. Results indicated that vacuum infrared drying increased the drying rate of banana bracts. The high temperatures of vacuum infrared drying at 60 and 70°C reduced drying time of banana bracts. Vacuum infrared drying decreased the drying time, and increased the drying rate of orange peels and Cistanche slices compared to hot air drying (Bozkir *et al.*, 2020; Jiang *et al.*, 2022). Swasdisevi *et al.* (2007) reported that the temperature of Far Infrared (FIR)-vacuum dryer affected the drying rate of banana slices. The moisture reduction rate increased with increasing drying temperature due to high moisture diffusivity and increasing temperature difference between the products and their surroundings.

Moisture, protein, lipid, crude fibre, and ash contents in wet basis of fresh banana bracts were 93.88, 0.98, 0.10, 1.87, and 0.67%, respectively. Moisture content and crude fibre of banana bract powder after oven drying and vacuum infrared drying at different temperatures ranged 4.63 - 5.91% and 15.27 - 15.75% (wb), respectively. Begum and Deka (2019a) reported that dried inner bracts contained 10.73% crude fibre, while Wickramarachchi and Ranamukhaarachchi (2005) reported that dehydrated banana blossom contained 17.41% (db) crude fibre.

Fresh banana bracts had a lighter colour, and less yellowness and browning index values compared to dried banana bracts, with *L**, *a**, *b**, and browning index of 87.44 ± 0.20, -4.95 ± 0.31, 23.27 ± 0.69, and 25.45 ± 0.85, respectively. Colour parameters of banana bract powders after tray and vacuum infrared drying are shown in Table 1. Banana bract powder dried by tray dryer at 70°C and vacuum infrared dryer at 60°C gave the highest lightness (*L**) values ($p < 0.05$). The *b** value, indicating the yellowness of tray-dried banana bract powder, was lower than infrared vacuum drying, with highest *b** values of tray and infrared samples dried at 60°C ($p < 0.05$). This result concurred with Bozkir *et al.* (2020) who reported that vacuum infrared drying of orange peel showed high yellowness value compared to tray and vacuum microwave drying. The browning index relates to the browning of dried banana powder. Banana bract powders dried by a vacuum infrared dryer had a significant effect on browning index. Bract powder dried using a tray dryer at 60°C and vacuum infrared dryer at 70°C had the highest browning index as the browning reaction occur during drying (Salehi *et al.*, 2017). The yellowness index followed the same trend of browning index, and the yellowness index of bract powder dried by vacuum infrared dryer was significantly higher than other dried samples.

Table 1. Colour parameters of banana bract powder after tray and vacuum infrared drying at different temperatures.

Drying method	Temperature (°C)	Colour			Browning index	Yellowness index
		*L**	*a**	*b**		
Tray dryer	50	79.21 ± 0.01^{c}	-1.86 ± 0.02^{e}	26.38 ± 0.01^{d}	37.12 ± 0.01^{e}	47.58 ± 0.02^{e}
	60	78.29 ± 0.01^{e}	-1.53 ± 0.01^{d}	27.38 ± 0.03^{b}	39.82 ± 0.04^{c}	49.96 ± 0.04^{c}
	70	79.68 ± 0.01^{a}	-1.97 ± 0.02^{f}	26.31 ± 0.01^{e}	36.62 ± 0.02^{f}	47.17 ± 0.02^{f}
Vacuum infrared dryer	50	78.83 ± 0.01^{d}	-1.08 ± 0.01^{b}	26.81 ± 0.01^{c}	38.89 ± 0.01^{d}	48.58 ± 0.02^{d}
	60	79.28 ± 0.01^{b}	-1.24 ± 0.01^{c}	28.01 ± 0.03^{a}	40.64 ± 0.06^{b}	50.47 ± 0.06^{b}
	70	75.40 ± 0.02^{f}	0.78 ± 0.01^{a}	27.36 ± 0.01^{b}	44.09 ± 0.02^{a}	51.84 ± 0.02^{a}

Mean values with the same lowercase superscripts within similar columns are not significantly different ($p > 0.05$).

Swelling power and solubility of banana bract dried by tray and vacuum infrared dryers at different drying temperatures were not significantly different (Table 2). The fibre structure of banana bract affected the kinetic of moisture uptake, with water tapped in the capillary fibre structure by hydrogen bonding or dipole forms (Jha *et al.*, 2021b). Water holding capacity depends on particle size, porosity, surface, and microstructure (Wen *et al.*, 2017). The water absorption of banana bract powder dried by a vacuum infrared dryer was higher than powder dried by a tray dryer. When vacuum infrared radiation energy is applied, the sample absorbs radiation energy that directly penetrates and causes rapid heating of the moisture inside the sample, leading to increased moisture vaporisation, and creating a porous structure from vapour pressure development (Nachisain *et al.*, 2016) that enhanced the water absorption capacity of vacuum infrared-dried samples. Jiang *et al*. (2022) stated that far infrared vacuum drying rapidly removed water, and caused pore expansion in the samples. Vacuum conditions also create greater stress, and produce a porous structure. Begum and Deka (2019a) stated that banana bract fibre with high hydration capacity can be applied as an anticaking and anti-sticking agent to reduce syneresis, and stabilise food systems. The water absorption of tray dried banana bract powder increased with increasing drying temperature that caused tissue collapse and cell damage, creating large spaces and enhancing the rehydration capacity of dried products (Wang *et al.*, 2018), while the water absorption capacity of powder dried by a vacuum infrared dryer did not significantly change when drying temperature increased ($p > 0.05$).

Oil absorption capacity relates to the absorption of organic compounds by the surface of substrates, and depends on the hydrophobic nature of the sample. Oil holding capacity relates to the chemical composition and porosity of the fibre (Yalegama *et al.*, 2013). Oil absorption capacity of tray-dried banana bract powder increased as drying temperature increased to 70°C, following the same

Table 2. Swelling power and solubility, water absorption, and oil absorption of banana bract powder after tray and vacuum infrared drying at different temperatures.

Drying method	Temperature (°C)	Swelling power (g/g)	Solubility (%)	Water absorption (g/g)	Oil absorption (g/g)
Tray dryer	50	31.90 ± 1.70	20.07 ± 1.58	28.02 ± 1.64^{c}	6.07 ± 0.78^{b}
	60	31.46 ± 1.76	20.94 ± 1.10	32.08 ± 1.54^{b}	6.51 ± 0.62^{ab}
	70	32.76 ± 1.57	19.57 ± 1.48	34.00 ± 1.60^{ab}	8.12 ± 1.46^{a}
Vacuum infrared dryer	50	32.59 ± 1.43	19.08 ± 1.36	35.18 ± 1.51^{a}	6.86 ± 0.55^{ab}
	60	32.48 ± 1.02	19.89 ± 1.34	35.99 ± 0.70^{a}	7.78 ± 0.99^{ab}
	70	31.58 ± 1.17	19.81 ± 1.84	34.78 ± 0.47^{a}	8.25 ± 1.42^{a}

Mean values with the same lowercase superscripts within similar columns are not significantly different ($p > 0.05$).

trend of water holding capacity, probably due to cell damage at high temperatures. However, oil absorption capacity of banana bract powder dried by a vacuum infrared dryer was not affected by drying temperature.

Bulk density indicates the easiness of powder products for packaging and transportation, and depends on particle size, contact point strength, and particle forces (Jha *et al.*, 2021a). Decrease in bulk density of tray-dried bract powder was observed with increasing drying temperature (Table 3). The bulk density and tapped density of banana bract powder dried by a vacuum infrared dryer were significantly lower than for tray-dried powder, indicating the compact structure of tray-dried bract powder with decreased void space causing high bulk density. The porous structure of vacuum infrared-dried powder decreased the bulk density and tapped density of the products. The Carr index (CI) indicates the powder flowability. Increased drying temperature for both tray drying and vacuum drying processes increased the Carr index value of the powder. Tray-dried banana bract powder showed significantly increased flowability compared to vacuum infrared dried bracts. A compact structure with reduced frictional force improved the flowability of the tray-dried samples.

Table 3. Bulk density, tapped density, and Carr index of banana bract powder after tray and vacuum infrared drying at different temperatures.

Drying method	Temperature (°C)	Bulk density (kg/m^3)	Tapped density (kg/m^3)	Carr index (%)
Tray dryer	50	396.72 ± 1.53^{a}	485.36 ± 3.44^{a}	18.26 ± 0.45^{e}
	60	385.59 ± 0.53^{b}	470.99 ± 0.79^{b}	18.13 ± 0.12^{e}
	70	379.96 ± 1.70^{c}	489.16 ± 4.03^{a}	22.32 ± 0.30^{c}
Vacuum infrared dryer	50	375.03 ± 0.92^{d}	468.53 ± 0.67^{b}	19.96 ± 0.27^{d}
	60	330.30 ± 0.17^{f}	434.63 ± 0.23^{d}	24.00 ± 0.01^{b}
	70	339.57 ± 3.38^{e}	457.39 ± 2.19^{c}	25.76 ± 1.07^{a}

Mean values with the same lowercase superscripts within similar columns are not significantly different ($p > 0.05$).

Different drying processes and temperatures affected the bioactive compounds in the banana bracts. The total phenolic content (TPC) of fresh banana bracts was 11.62 ± 0.16 (mg GAE/g DW), with TPC and antioxidant activity of banana bract powders presented in Table 4. Increase in TPC was observed for the dried samples compared to the fresh samples. Phenolic compounds in fruits and vegetables are present in bound form or linked to cell wall materials. Thermal treatment releases phenolic compounds by breaking the cellular structure (Valadez-Carmona *et al.*, 2017). The TPC of

Table 4. Total phenolic content and antioxidant activity (DPPH free radical scavenging and FRAP) of banana bract powder after tray and vacuum infrared drying at different temperatures.

Drying method	Temperature (°C)	Total phenolic content (mg GAE/g DW)	DPPH· (mg TE/g DW)	FRAP (mg TE/g DW)
Tray dryer	50	21.15 ± 0.50^{ab}	63.88 ± 1.22^{a}	29.33 ± 0.78^{ab}
	60	20.10 ± 0.47^{bc}	63.49 ± 1.27^{a}	28.29 ± 2.32^{b}
	70	19.46 ± 0.65^{c}	59.66 ± 0.53^{b}	29.06 ± 0.52^{ab}
Vacuum infrared dryer	50	21.97 ± 0.26^{a}	64.80 ± 1.89^{a}	31.82 ± 2.36^{a}
	60	19.32 ± 0.75^{c}	59.40 ± 1.74^{b}	28.01 ± 1.16^{b}
	70	20.53 ± 1.05^{bc}	57.15 ± 1.25^{b}	29.99 ± 1.49^{ab}

Mean values with the same lowercase superscripts within similar columns are not significantly different ($p > 0.05$).

tray-dried and vacuum infrared-dried bract powder was not significantly different at the same drying temperature. These results concurred with Bozkir *et al.* (2020) who found that the TPC of tray-dried and vacuum infrared-dried orange peel was not significantly different ($p > 0.05$), while TPC of the powder decreased with increasing drying temperature. Decrease of TPC in the samples as drying temperature increased occurred because of the thermal degradation of phenolic compounds by oxidation reactions or covalent bond cleavage (Valadez-Carmona *et al.*, 2017). Jiang *et al*. (2022) reported that Cistanche slices dried by far infrared vacuum dying at 55°C gave the highest TPC value, which decreased when the samples were dried at 60 - 65°C. High temperature during infrared vacuum drying causes polymerisation and oxidation of phenolics, and depolymerisation of high molecular weight phenolics. Begum and Deka (2019a) reported that the inner bracts of the banana flower contained eight free phenolics including catechin hydrate, chlorogenic, syringic, *p*-coumaric, ferulic, salicylic, quercetin dihydrate, and quinic acid, while the bound phenolics in the inner bracts were ferulic acid and salicylic acid.

Antioxidant activities obtained from different assays reflect relative differences in the ability of antioxidant compounds in the extract. The DPPH assay measures the ability of the extract to donate hydrogen to the radical, while the FRAP assay measures the electron donating abilities of antioxidants. The DPPH and FRAP values of fresh banana bracts were 29.14 ± 0.11 and 6.95 ± 0.07 mg TE/g DW, respectively. An increase in DPPH and FRAP values of the dried samples was observed compared to the fresh samples. DPPH values of tray-dried and vacuum infrared-dried powders significantly decreased as temperature increased from 50 to 70°C. This decrease in DPPH values resulted from a decrease in TPC when the samples were treated at high temperatures, which provided less hydrogen to stabilise DPPH radicals. The FRAP values of banana bract tray-dried powder were not significantly different ($p > 0.05$), while the FRAP values of banana bract powder dried at 70°C were the highest.

Glucose adsorption of vacuum infrared-dried banana bract powder was significantly higher (0.69 - 0.74 mM) than tray-dried banana bract powder (0.59 - 0.64 mM) ($p < 0.05$). Vacuum infrared-dried banana bracts effectively absorbed glucose due to their porous structure which enhanced water glucose adsorption. Arun *et al.* (2017) reported that 100 mg of soluble and insoluble dietary fibre from plantain inflorescence (PI) effectively adsorbed 0.4 - 0.5 mM of glucose. Dietary fibre decreases the absorption and digestion of carbohydrates, resulting in lowered postprandial blood glucose levels, and reduces glucose adsorption due to its viscous and gel-forming properties which entrap glucose within the network (Ou *et al.*, 2001).

Inhibition of carbohydrate digestive enzymes, including α-amylase and α-glucosidase, slows down the hydrolysis of starch, and this decreases blood sugar levels. Results indicated that α-amylase inhibition of banana bract tray-dried powder at 60°C was significantly higher than samples dried at 50 and 70°C, while powder dried by a vacuum infrared dryer at 70°C gave the highest value. Sheng *et al.* (2017) reported that phytosterols in banana flowers may bind to α-amylase, and cause a conformational change that reduces its activity.

α-Glucosidase inhibition lowers the absorption rate of glucose in digestive systems, and decreases postprandial plasma glucose levels. Results indicated that vacuum infrared-dried banana bract powder effectively inhibited α-glucosidase activity compared to tray-dried powder. The tray dried samples showed no statistically significant differences in α-glucosidase inhibition at different drying temperatures. By contrast, drying at high temperatures affected α-glucosidase inhibition of vacuum infrared dried powder, with drying at 70°C giving the highest inhibition of α-glucosidase at 33.02% (Table 5). Sheng *et al.* (2017) reported that phytosterols in banana flowers can change the activity site of α-glucosidase for binding to the substrate. These results concurred with Chiang *et al.* (2021) who reported that banana bract extracted with 75% ethanol at room temperature exhibited high α-glucosidase inhibition (27.38%) compared to α-amylase inhibition (12.70%). The results demonstrated that banana bracts could have potential in controlling blood glucose level, and could be used as functional ingredients in food products.

Table 5. Glucose adsorption, α-amylase inhibition, and α-glucosidase inhibition of banana bract powder after tray and vacuum infrared drying at different temperatures.

Drying method	Temperature (°C)	Glucose adsorption (mM)	α-Amylase inhibition (%)	α-Glucosidase inhibition (%)
Tray dryer	50	0.63 ± 0.01^{d}	16.24 ± 1.07^{b}	22.03 ± 1.43^{c}
	60	0.59 ± 0.01^{e}	21.71 ± 1.48^{a}	20.07 ± 1.93^{c}
	70	0.64 ± 0.02^{d}	15.04 ± 0.59^{bc}	22.38 ± 2.30^{c}
Vacuum infrared dryer	50	0.73 ± 0.01^{b}	13.68 ± 0.78^{c}	20.17 ± 1.64^{c}
	60	0.69 ± 0.02^{c}	14.02 ± 0.30^{c}	28.53 ± 1.23^{b}
	70	0.74 ± 0.01^{a}	15.90 ± 0.51^{b}	33.02 ± 2.30^{a}

Mean values with the same lowercase superscripts within similar columns are not significantly different ($p > 0.05$).

Conclusion

The yellowness and browning index values of banana bract powder dried by a tray dryer were lower than for powder dried by an infrared vacuum dryer. Increased water absorption of tray-dried banana bract powder was observed with increasing drying temperature, while vacuum infrared-dried banana bract powder had higher water absorption index compared to tray-dried powder. Bulk density and tapped density of banana bract powder dried by a vacuum infrared dryer were significantly lower, while the Carr index value was higher than for samples dried by a tray dryer. The TPC and DPPH values of banana bract powder dried by a tray dryer and vacuum infrared dryer decreased with increasing drying temperature. Vacuum infrared-dried powder exhibited higher glucose adsorption than tray-dried powder. Tray drying at 60°C effectively inhibited α-amylase in banana bract powder, while the inhibition of α-glucosidase was enhanced by vacuum infrared drying at 70°C.

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References

Arun, K. B., Thomas, S., Reshmitha, T. R., Akhil, G. C. and Nisha, P. 2017. Dietary fibre and phenolic-rich extracts from *Musa paradisiaca* inflorescence ameliorates type 2 diabetes and associated cardiovascular risks. Journal of Functional Foods 31(1): 198-207.

Association of Official Agricultural Chemists (AOAC). 2005. Official methods of analysis of AOAC International. 18th ed. United States: AOAC.

Bashary, R. and Khatik, G. L. 2019. Design, and facile synthesis of 1,3 diaryl-3-(arylamino) propan-1-one derivatives as the potential alpha-amylase inhibitors and antioxidants. Bioorganic Chemistry 82:156-162.

Begum, Y. A. and Deka, S. C. 2019a. Chemical profiling and functional properties of dietary fibre rich inner and outer bracts of culinary banana flower. Journal of Food Science and Technology 56(12): 5298-5308.

Begum, Y. A. and Deka, S. C. 2019b. Effect of processing on structural, thermal, and physicochemical properties of dietary fibre of culinary banana bracts. Journal of Food Processing and Preservation 43: e14256.

Bozkir, H., Tekgui, Y. and Erten, E. S. 2020. Effects of tray drying, vacuum infrared drying, and vacuum microwave drying techniques on quality characteristics and aroma profile of orange peels. Journal of Food Process Engineer 44: e13611.

Chiang, S. H., Yang, K. M., Lai, Y. C. and Chen, C. W. 2021. Evaluation of the *in vitro* biological activities of banana flower and bract extracts and their bioactive compounds. International Journal of Food Properties 24(1):1-16.

Falleh, H., Ksouri, R., Lucchessi, M. E., Abdelly, C. and Magné, C. 2012. Ultrasound-assisted extraction: Effect of extraction time and solvent power on the levels of polyphenols and antioxidant activity of *Mesembryanthemum edule* L. Aizoaceae shoots. Tropical Journal of Pharmaceutical Research 11(2): 243-249.

Jha, P., Meghwal, M. and Prabhaker, P. K. 2021b. Microwave drying of banana blossoms (*Musa acuminata*): Mathematical modeling and drying energetics. Journal of Food Processing and Preservation 43: e15717.

Jha, P., Meghwal, M., Prabhakar, P. K. and Singh, A. 2021a. Exploring effects of different pretreatments on drying kinetics, moisture diffusion, physico-functional, and flow properties of banana flower powder. Journal of Food Processing and Preservation 45: e15356.

Jiang, C., Wan, F., Zang, Z., Zhang, Q. and Xu, Y. 2022. Influence of far-infrared vacuum drying on drying kinetics and quality characteristics of Cistanche slices. Journal of Food Processing and Preservation 43: e17144.

Lee, S. H., Beak, S. M., Jeong, I., Heo, W., Hwang, K. A., Han, B. K. and Kim, Y. J. 2022. Anti-browning and oxidative enzyme activity of rice bran extract treatment on freshly cut 'Fuji' apple. Agronomy 12: 86.

Nachisain, M., Jamradloedluk, J. and Niamnuy, C. 2016. Application of combined far-infrared radiation and air convection for drying of instant germinated brown rice. Journal of Food Process Engineering 39: 306-318.

Ou, S., Kwok, K., Li, Y. and Fu, L. 2001. *In vitro* study of possible role of dietary fiber in lowering postprandial serum glucose. Journal of Agricultural and Food Chemistry 49: 1026-1029.

Raja, K. S., Taip, F. S., Azmi, M. M. Z. and Shishir, M. R. I. 2019. Effect of pre-treatment and different drying methods on the physicochemical properties of *Carica papaya* L. leaf powder. Journal of the Saudi Society of Agricultural Science 18: 150-156.

Ramu, R., Shirahatti, P. S., Zameer, F., Ranganatha, L. V. and Prasad, M. N. N. 2014. Inhibitory effect of banana (*Musa* sp. var. Nanjangud rasa bale) flower extract and its constituents Umbelliferone and Lupeol on α-glucosidase, aldose reductase and glycation at multiple stages. South African Journal of Botany 95(1): 54-63.

Salehi, F., Kashaninejad, M. and Jafarianlari, A. 2017. Drying kinetics and characteristics of combined infrared-vacuum drying of button mushroom slices. Heat and Mass Transfer 53: 1751-1759.

Shao, Y., Xu, F., Sun, X., Bao, J. and Beta, T. 2014. Identification and quantification of phenolic acids and anthocyanins as antioxidants in bran, embryo and endosperm of white, red, and black rice kernels (*Oryza sativa* L.). Journal of Cereal Science 59(2): 211-218.

Sheng, Z., Dai, H., Pan, S. and Ai, B. 2017. Phytosterols in banana (*Musa spp*.) flower inhibit α- amylase hydrolysations and glycation reaction. International Journal of Food Science and Technology 52:171-179.

Swasdisevi, T., Devahastin, S., Ngamchum, R. and Soponronnarit, S. 2007. Optimization of a drying process using infrared vacuum drying of Cavendish banana slices. Songklanakarin Journal of Science and Technology 29(3): 809-816.

Thaweesang, S. 2019. Antioxidant activity and total phenolic compounds of fresh and blanching

banana blossom (*Musa ABB CV. Kluai "Namwa"*) in Thailand. Materials Science and Engineering 639: 1-7.

Thuengtung, S., Niwat, C., Tamura, M. and Ogawa, Y. 2018. *In vitro* examination of starch digestibility and changes in antioxidant activities of selected cooked pigmented rice. Food Bioscience 23(1): 129-136.

Valadez-Carmona, L., Plazola-Jacinto, C. P., Hernández-Ortega, M., Hernández-Navarro, M. D., Villarreal, F., Necoechea-Mondragón, H., ... and Ceballos-Reyes, G. 2017. Effects of microwaves, hot air and freeze-drying on the phenolic compounds, antioxidant capacity, enzyme activity and microstructure of cacao pod husks (*Theobroma cacao* L.). Innovative Food Science and Emerging Technology 41: 378-386.

Varela, C., Aghababaei, F., Cano-Sarabia, M., Turitich, L., Trujillo, A. J. and Ferragut, V. 2022. Characterization and oxidation stability of spray-dried emulsions with omega-3 oil and buttermilk processed by ultra-high-pressure homogenization (UHPH). LWT - Food Science and Technology 162: 113493.

Wang, J., Law, C.-L., Nema, P. K., Zhao, J.-H., Liu, Z.-L., Deng, L.-Z., ... and Xiao, Z.-L. 2018. Pulsed vacuum drying enhances drying kinetics and quality of lemon slices. Journal of Food Engineering 24: 129-138.

Wen, Y., Niu, M., Zhang, B., Zhao, S. and Xiong, S. 2017. Structural characteristics and functional properties of rice bran dietary fiber modified by enzymatic and enzyme-micronization treatments. LWT - Food Science and Technology 75: 344-351.

Wickramarachchi, K. S. and Ranamukhaarachchi, S. L. 2005. Preservation of fiber-rich banana blossom as a dehydrated vegetable. ScienceAsia 31: 265-271.

Yalegama, L. L. W. C., Karunaratne, D. N., Sivakanesan, R. and Jayasekara, C. 2013. Chemical and functional properties of fibre concentrates obtained from by-products of coconut kernel. Food Chemistry 141: 124-130.