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Performance Evaluation of a Spray Dryer Based on Capacity and Yield using Biancaea sappan Extract

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Abstract
This study evaluates the performance of pressure nozzle type spray dryer. Maximum evaporation capacity was tested using water under various nozzle air pressures, airflow rates and at two inlet air temperatures. Solution of biancaea sappan extract mixed with maltodextrin were used to analyze powder yield, wall deposition, color of the powder, and efficiency of the spray dryer. An increase of nozzle air pressure and airflow rate gives finer atomization resulting in higher heat transfer. Combined with an increase in inlet air temperature, maximum evaporation capacity is achieved and can increase the powder yield of the spray dryer due to better moisture removal. Significant wall deposition was found in the head, drying chamber and cyclone duct. Visual analysis of the powder indicated that higher temperatures and prolonged residence time advanced the Maillard reaction, darkening the powder and could degrade its texture. A rather significant amount of powder loss was observed which is likely caused by fine particles leaving with exhaust air.

Keywords: biancaea sappan extract, evaporative capacity, Maillard reaction, powder yield, spray dryer, wall deposition

INTRODUCTION

The interest in using natural dyes derived from various organic sources instead of synthetic dyes that have been extensively used in the textile industry has grown in recent years due to the move toward sustainability and the awareness of the harmful substances that are contained in the synthetic dyes that have various adverse effects to the environment and living organisms.[1] The use of natural dyes is not only able to reduce the harmful effect of synthetic dyes due to its environmentally friendly and biodegradable properties, it also have some potential medicinal values thus enhancing the functional properties of textiles.[2]

To preserve natural dyes properties, they are often kept in powder form while in storage. Drying will reduce the water content thus reducing microbial degradation and giving it longer shelf life.[3]

[1] Diem Thi Kieu Le, Tuan Minh Le, and Ha Manh Bui, "Natural Dyes from Diospyros Mollis: A Sustainable Alternative for the Textile Industry," *Sustainable Chemistry One World* 5 (2025): 100049, https://doi.org/10.1016/j.scowo.2025.100049.
[2] Jin Fang, Chen Meng, and Guangzhi Zhang, "Agricultural Waste of Ipomoea Batatas Leaves as a Source of Natural Dye for Green Coloration and Bio-Functional Finishing for Textile Fabrics," *Industrial Crops and Products* 177 (2022): 114440, https://doi.org/10.1016/j.indcrop.2021.114440.
[3] Usdyana Attahmid Nur Fitriani, Muhammad Yusuf, and Fika Soleha Ilyas, "Spray Drying of Rosella (Hibiscus Sabdariffa L.) Powder: Effect of Shelf Life on Physicochemical Properties and Cyanidin 3-O—Glucoside," in *IOP*

Besides the longer shelf life, keeping natural dyes in powder form will be more practical and flexible since the dyes will take up less space in powder form and the viscosity of the solution of the natural dyes can be adjusted accordingly.[4] An encapsulation technique can be used to protect natural dyes from environmental factors and can also be scaled to industrial scale.[5]

Spray drying is an encapsulation method that is commonly used in a wide range of industries including food, pharmaceuticals, and chemicals.[6] A spray dryer is a machine that turns liquid solution into powder form. It starts with atomizing a feed liquid solution by pressure nozzle or a rotary atomizer. The feed solution then turns into tiny droplets that encounter hot inlet gas, evaporating the moisture in the droplets. The droplets are then carried into the cyclone separator, separating the powder with the gas flow.

Spray drying parameters (feed flow rate, inlet temperature, atomization pressure) will influence the formation of the droplets. A proper atomization of the feed solution is necessary to achieve a large surface area-to-mass ratio, giving a robust heat transfer with plenty of surface area for moisture to be evaporated by the hot inlet gas and thus a powder with lower moisture content and quicker drying rate with higher feed flow rate can be obtained.[7] If the atomization pressure is found to be insufficient, the feed solution will be improperly atomized resulting in an inconsistent particles size and can cause build-up on the nozzle with feed solution dripping into the drying chamber reducing yield.[8]

Besides the drying rate, droplets sizes will also have an influence on the particle size of the powder.[9] While a small droplets size is beneficial for a quicker drying rate, a too small of droplets size will result in particles that are too small which will lead to lump formation during rehydration resulting in poor reconstitution and flowability.[10] Therefore, optimizing the spray dryer parameters is necessary to balance the process efficiency with the quality of the product.

A study on the effect of hot gas inlet temperature has been conducted with an increase of temperature leads to a lower moisture content in the powder while also suggesting that the hot gas inlet temperature should be high enough to prevent wall-sticking of the powder to the dryer wall due to excessive moisture and thus reducing yield.[11] A higher inlet temperature also resulted in an increase of darkness due to the formation of brown pigments (melanoidins) on the later stages of Maillard

Conference Series: Earth and Environmental Science, vol. 755, 2021, 12002, https://doi.org/10.1088/1755-1315/755/1/012002.

[4] Huswatun Hasanah, Daimon Syukri, and Ismed Ismed, "A Effect of Maltodextrin Concentration on Antioxidants Activity and Stability of Natural Coloring Powder of Secang Wood (Caesalpinia Sappan L) in Various Conditions of Ph and Temperature," *Andalasian International Journal of Agriculture and Natural Sciences (AIJANS)* 3, no. 02 (2022): 76–95, https://doi.org/10.25077/aijans.v3.i02.1-19.2022.

[5] Michelle Heck Machado et al., "Microencapsulation by Spray Drying of Red Cabbage Anthocyanin-Rich Extract for the Production of a Natural Food Colorant," *Biocatalysis and Agricultural Biotechnology* 39 (2022): 102287, https://doi.org/10.1016/j.bcab.2022.102287.

[6] Pavithra Sundararajan et al., "Driving Spray Drying towards Better Yield: Tackling a Problem That Sticks Around," *Pharmaceutics* 15, no. 8 (2023): 2137, https://doi.org/10.3390/pharmaceutics15082137.

[7] Andri Cahyo Kumoro et al., "A Brief Overview of Spray Drying Technology and Its Potential in Food Applications," *Journal of Human, Earth, and Future* 5, no. 2 (2024): 279–305, https://doi.org/10.28991/HEF-2024-05-02-09.

[8] Anneloes P van Boven et al., "Analysis on Particle Morphology Development during Pilot-Scale Spray Drying of Maltodextrins," *Drying Technology* 43, no. 5 (2025): 840–57, https://doi.org/10.1080/07373937.2025.2472390.

[9] Fei Zhang et al., "Mathematical Model and Numerical Investigation of the Influence of Spray Drying Parameters on Granule Sizes of Mold Powder," *Particuology* 85 (2024): 280–95, https://doi.org/10.1016/j.partic.2023.06.017.

[10] Ireneusz Zbicinski, Krzysztof Ciesielski, and Bangguo Ge, "Mechanism of Particle Agglomeration for Single and Multi-Nozzle Atomization in Spray Drying: A Review," *Processes* 10, no. 4 (2022): 727, https://doi.org/10.3390/pr10040727.

[11] Rungthiwa Methaapanon et al., "The Production of Microencapsulated Methyl Palmitate Phase Change Materials via Different Scales of Spray Drying Process," *Advanced Powder Technology* 36, no. 5 (2025): 104853, https://doi.org/10.1016/j.apt.2025.104853.

reaction.[12]

Optimization of these parameters is essential to ensure quality products that are up to standard with maximum efficiency. While various studies have been done using food and pharmaceuticals products, studies done specifically for using natural dyes are still limited. This study aims to fill this gap by conducting performance testing of a co-current spray dryer prototype to produce natural dyes powder. Maximum evaporation capacity of the spray dryer will be tested using water with inlet air temperature, air pressure and airflow rate as its variable. And then the yield with efficiency of the spray dryer will be tested at two inlet temperature settings with *Biancaea sappan* wood extract mixed with 15 wt.% maltodextrin. The yield, wall deposition and the color result of the powder will be evaluated.

METHOD

Biancaea sappan woodchips were purchased from UD. Bima Kunting (Solo, Indonesia). Maltodextrin was purchased from CV. Subur Kimia Jaya (Semarang, Indonesia)

Biancaea sappan woodchips were prepared by soaking it in water with a ratio of 1:8 w/v for 12 hours. The mixture was then boiled for 2 hours and then let cool to room temperature (32 °C). After the mixture was cooled off, it was then filtered through a thin fabric to remove solid particulates from the extract. The obtained *biancaea sappan* wood extract was then mixed with 15 wt.% maltodextrin then stirred until the solution was homogeneous and ready to be used as the spray dryer feed.

The spray dryer used was a pressure nozzle co-current double wall type spray dryer prototype with a single stage cyclone. Feed flow rate was controlled by a peristaltic pump. A pressure nozzle with orifice diameter of 0.8 mm was used. Air for the pressure nozzle was provided by a 1 HP air compressor with a supply pressure of 2 to 4 bar and airflow rate of 15 to 30 L/min. Hot air inlet was supplied with a hot air gun with temperatures of 200 °C and 230 °C. All the tests were done at 32 °C room temperature and relative humidity (RH) of 80%.

Testing of the spray dryer maximum evaporation capacity was tested under various pressure and airflow rates for the pressure nozzle using a continuous feed of water with inlet air temperature of 200 °C and 230 °C. The exit of the drying chamber was checked periodically to ensure no condensation has formed on the wall of the drying chamber. The maximum feed rate was recorded when the spray dryer has been running continuously on the current feed rate for 15 minutes with no condensation occurring.

Testing of the spray dryer powder yield was tested with 1 liter of feed solution at 200 °C and 230 °C inlet air temperature. The feed rate was set at 500 mL/h. Powder yield was weighed and visually inspected for color on each section of the spray dryer. The spray dryer efficiency was calculated using equation:

$$\eta(\%) = \frac{Mass\ of\ total\ powder\ yield\ (g)}{Mass\ of\ total\ solid\ in\ feed\ solution\ (g)} \times 100\%$$

[12] Zelin Zhou and Timothy Langrish, "Color Formation and Maillard Reactions during the Spray Drying Process of Skim Milk and Model Systems," *Journal of Food Process Engineering* 45, no. 1 (2022): e13936, https://doi.org/10.1111/jfpe.13936.

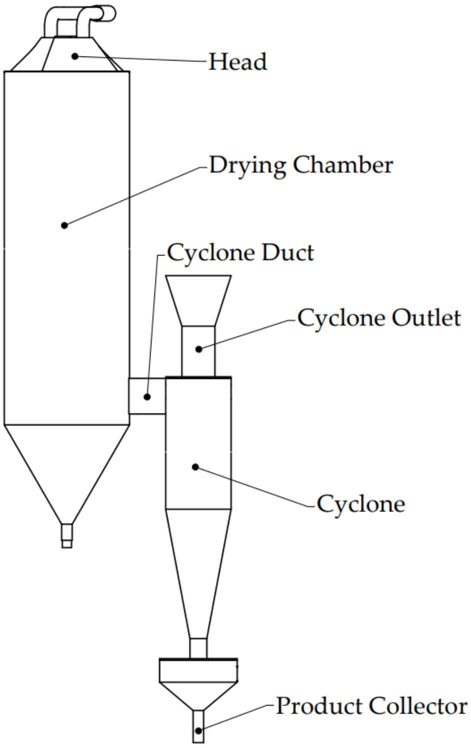

Figure 1. Section of the spray dryer.

RESULTS AND DISCUSSION

Maximum Evaporation Capacity

In the evaporation test with water under different air pressure and airflow rates for the pressure nozzle, it is concerned whether the evaporation capacity of the spray dryer is improved. The result of the experiment with air pressure from 2 to 4 bar and airflow rate from 15 L/min to 30 L/min for the spray nozzle at 200 °C of inlet air temperature is shown on Fig. 2.

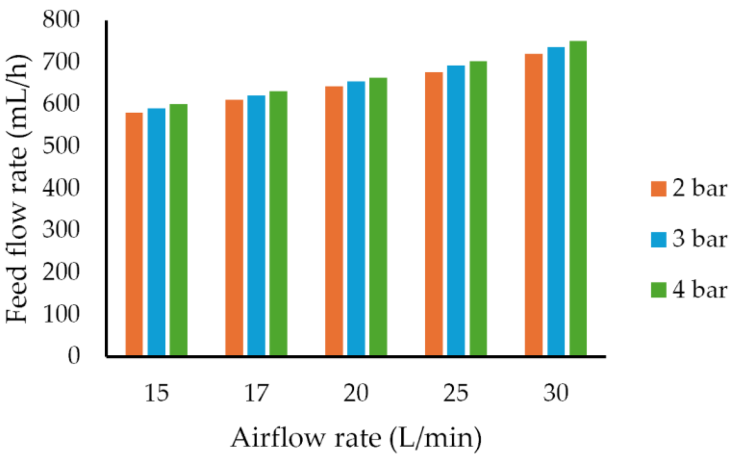

Figure 2. Maximum evaporation capacity at 200 °C of inlet air temperature under different pressure and airflow rates for the spray nozzle.

Based on the results of Fig. 2, maximum evaporation capacity of 750 mL/h was reached with 4 bar of air pressure and 30 L/min of airflow rate. The result showed a linear trend, with an increase of both air pressure and airflow rate for the pressure nozzle the evaporation capacity of the spray dryer was improved. Increasing air pressure for the pressure nozzle produces finer and more uniform droplets, increasing the total surface area of the droplets and thus more heat transfer occurred and a quicker drying rate can be achieved.[13] Increasing airflow rate also helped promote atomization performance of the pressure nozzle resulting in a more even distribution of droplets.[14] With finer and more controlled droplets, more feed solution can be evaporated and thus feed flow rate can be increased. It should be noted however, with an increase in feed flow rate the droplet size will increase.[15] The viscosity of the feed solution also affects the droplet size with a higher viscosity fluid resulted in a larger droplets.[16] If particle size of the powder is a main concern, air pressure and airflow rate for the pressure nozzle and the viscosity of feed solution and feed flow rate needs to be adjusted accordingly to achieve the desired particle size.

Since the pressure nozzle relies on an air compressor to operate, the air compressor duty cycle should be an important aspect to be considered. The duty cycle of the air compressor was recorded and shown on Fig. 3 from the various air pressure and airflow rates that have been tested.

It is shown in Fig. 3 that to achieve 4 bar of air pressure and 30 L/min of airflow rate for the pressure nozzle to run the spray dryer at maximum evaporation capacity, it requires running the air compressor at 100% duty cycle which means the air compressor need to run constantly to supply enough air for the demand that the pressure nozzle need. Running the air compressor continuously will not let the air compressor to cool off and can cause it to overheat. Running the air compressor above the recommended duty cycle from the manufacturer for extended period could result in damage to the air compressor, reducing the air compressor performance overtime and could result in total failure of the air compressor.

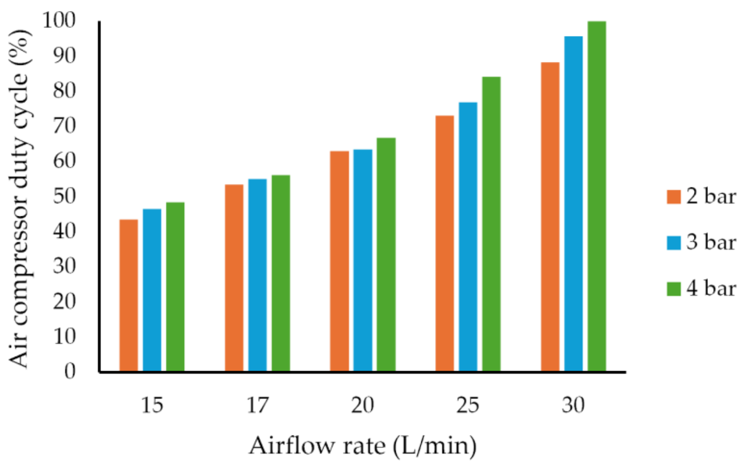

Figure 3. Air compressor duty cycle under various air pressure and airflow rates for the pressure nozzle.

To ensure the reliability of the whole system, the pressure nozzle needs to be run at lower air pressure and lower airflow rate setting to not overload the air compressor especially if the spray dryer were to be run at an extended amount of time. And with lower air pressure and airflow rates, the evaporation capacity of the spray dryer is also reduced. If maximum evaporation capacity of the spray dryer is at most important, then a more powerful air compressor that can flow more air or an air compressor that is designed for continuous use is a must.

Fig. 4 presents the difference of evaporation capacity of the spray dryer on 200 °C and 230 °C

[13] Huitian Peng et al., “Influence of Pressure Combination on Atomization and Dust Reduction Performance of Air-Atomizing Nozzles,” *Powder Technology* 476 (2026): 122333, https://doi.org/10.1016/j.powtec.2026.122333.

[14] Xin Ma et al., “Effect of Airflow Rate and Temperature on the Atomization Characteristics of Biodiesel in Internal and External Flow Fields of the Pressure Swirl Nozzle,” *Energy* 253 (2022): 124112, https://doi.org/10.1016/j.energy.2022.124112.

[15] Peng et al., “Influence of Pressure Combination on Atomization and Dust Reduction Performance of Air-Atomizing Nozzles.”

[16] Cooper Welch et al., “Experimental Investigation of Spray Drying Breakup Regimes of a PVP-VA 64 Solution Using High-Speed Imaging,” *Pharmaceutics* 16, no. 12 (2024): 1547, https://doi.org/10.3390/pharmaceutics16121547.

inlet air temperature with 4 bar of air pressure and airflow rate of 15, 20 and 30 L/min. In general, there is an increase of about 33% of evaporation capacity by increasing the inlet temperature from 200 °C to 230 °C across all airflow rates that are tested with maximum evaporation capacity achieved at 1000 mL/h. The increase of inlet air temperature increases the mass heat transfer and promotes surface vapor migration of water droplets, increasing the amount of water that can be evaporated in the drying chamber.[17] With more evaporation possible, an increase in feed flow rate can be done to take advantage of it.

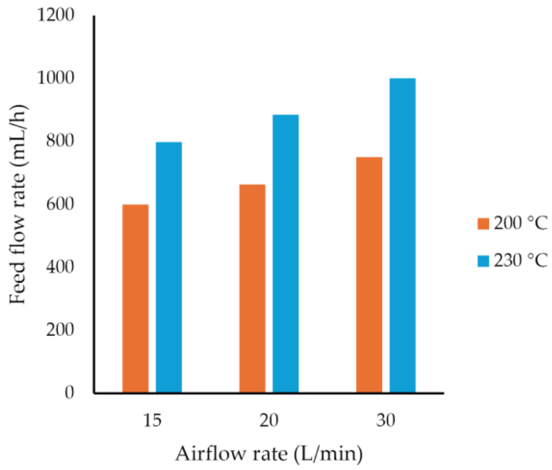

Figure 4. Maximum evaporation capacity of the spray dryer with inlet air temperature of 200 °C and 230 °C at varying airflow rates.

Powder Yield

Testing of yield of the spray dryer was tested using *biancaea sappan* extract mixed with 15 wt.% maltodextrin (150 g). Testing was done on 4 bar of air pressure and 17 L/min of airflow rate for the pressure nozzle. Inlet air temperature was set at 200 °C and 230 °C with each test, 1 liter of feed solution with 500 mL/h feed flow rate was used.

Total yield of the spray dryer was counted both from the amount of powder that has been collected by the cyclone and the wall deposition of the spray dryer. Table 1 presents the findings of this test.

The result in Table 1 suggests that increasing the inlet temperature from 200 °C to 230 °C positively influenced the final product recovery, with the powder collected by the cyclone increasing from 34.6 g to 39.8 g. This increase in yield on powder collected is likely due to enhanced water removal from the feed solution and the higher heat and mass transfer caused by the higher inlet air temperature.[18]

Table 1. Yield produced by the spray dryer at inlet temperature of 200 °C and 230 °C with 150 grams of total solid (maltodextrin) in 1 liter of *biancaea sappan* extract solution.

Section	Yield (g)	
	200 °C	**230 °C**
Head	1.2	1.2
Drying Chamber	30.6	32.8
Cyclone Duct	5.5	5.9
Cyclone	0.4	0.6
Cyclone Outlet	0.3	0.4
Product Collector	34.6	39.8
Total Yield	72.6	80.7

[17] Jamille Coelho Coimbra et al., "CFD Modeling of Spray Drying of Fresh Whey: Influence of Inlet Air Temperature on Drying, Fluid Dynamics, and Performance Indicators," *Digital Chemical Engineering* 12 (2024): 100178, https://doi.org/10.1016/j.dche.2024.100178.

[18] Poliana Moser, Adilson Roberto Locali-Pereira, and Vânia Regina Nicoletti, "Optimization of Spray Drying Process of Buriti Oil-Loaded Bilayer Emulsions," *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 698 (2024): 134516, https://doi.org/10.1016/j.colsurfa.2024.134516.

Wall Deposition

Based on Table 1 result, significant powder deposition was observed in the head, drying chamber and cyclone duct of the spray dryer while there is only a slight dusting on the cyclone and cyclone outlet wall. 1.2 g of powder was found sticking on the head of the spray dryer on both tests with wall deposition concentrated on the vanes that direct the incoming hot air inlet into the drying chamber. This phenomenon could be caused by the ever-changing pressure gradients inside the drying chamber influenced by the variation in system airflow rate that comes from the hot air gun and the pressure nozzle and turbulence induced by the shape of the inlet air piping and the guiding vanes, causing the trajectories of the particles going back to the roof of the drying chamber. [19]

A significant amount of wall deposition was found inside the drying chamber of the spray dryer. 30.6 g and 32.8 g of wall deposition mass with 200 °C and 230 °C inlet air temperature respectively. While the powder that sticks to the wall of the drying chamber was only minor, a significant portion of the wall deposition build-up was found on the conical section at the bottom of the chamber on both cases. While some build-up on the conical section of the drying chamber was to be expected on a co-current spray dryer, the excessive build-up could be attributed to the stickiness of the powder produced.[20] A study found that a drying chamber with an insulated wall which makes the drying chamber warmer tend to experience much more wall deposition.[21] Another cause could be from the lack of airflow velocity from the system and a large particle size from insufficient atomization by the pressure nozzle. The lack of airflow velocity is insufficient to maintain particle suspension against gravitational pull. And with larger particle size resulting in a heavier particle, it will make particle settling faster on the same airflow velocity. Heavier particles require higher airflow velocity to maintain particle suspension. This phenomenon can also be seen on the cyclone duct where 5.5 g and 5.9 g of wall deposition mass with 200 °C and 230 °C inlet air temperature respectively has its significant wall deposition occurring on the floor of the duct with just some minor dusting on the wall and the roof of the cyclone duct, suggesting a limitation of aerodynamic within the system.

Visual Inspection of Powder

Visual inspection for the color of the collected powder by the cyclone for both tests with inlet temperature of 200 °C and 230 °C were shown in Fig. 5.

Based on Fig. 5, it could be seen that *biancaea sappan* extract produces an orange color powder, with a slightly darker orange color for inlet temperature of 230 °C compared to ones at 200 °C due to higher temperature favoring Maillard reaction producing brown pigment which happens on higher temperature. [22]

Some color and texture difference was found with the wall deposition. Powder comparison of the collected powder with the wall deposition is shown in Fig. 6.

[19] Sundararajan et al., "Driving Spray Drying towards Better Yield: Tackling a Problem That Sticks Around."
[20] E De Pauw et al., "Drying Behaviour and Visualization of Surfactants after Co-Spray Drying of Surfactant-Stabilized Aqueous Suspensions," *International Journal of Pharmaceutics* 643 (2023): 123231, https://doi.org/10.1016/j.ijpharm.2023.123231.
[21] Sara Moradi Maryamnegari et al., "Effects of Thermal Boundary Conditions on the Performance of Spray Dryers," *Journal of Food Engineering* 338 (2023): 111250, https://doi.org/10.1016/j.jfoodeng.2022.111250.
[22] Mónica Umaña et al., "Spray Drying of Double-Layer Emulsion Stabilised with an Orange Residue: Effect of Process Parameters and Collection Position," *Foods* 14, no. 16 (2025): 2919, https://doi.org/10.3390/foods14162919.

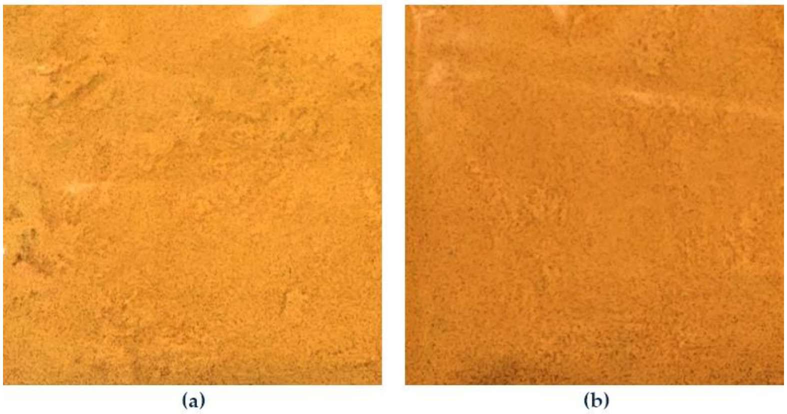

Figure 5. Color of the collected powder by the cyclone at inlet temperature of (a) 200 °C and b) 230 °C.

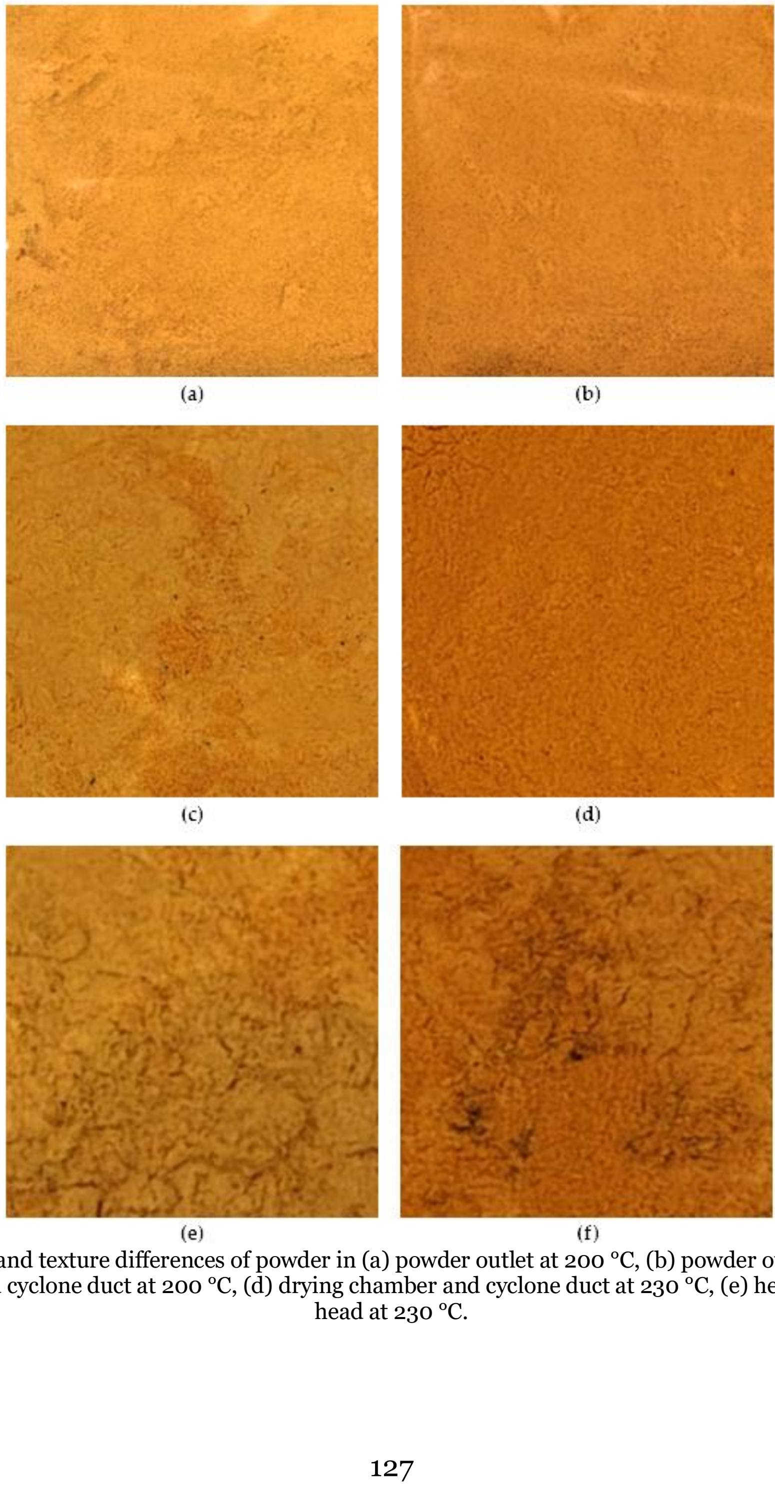

Figure 6. Color and texture differences of powder in (a) powder outlet at 200 °C, (b) powder outlet at 230 °C, (c) drying chamber and cyclone duct at 200 °C, (d) drying chamber and cyclone duct at 230 °C, (e) head at 200 °C, and (f) head at 230 °C.

While the powder collected by the cyclone was finely textured and has a uniform color, the same could not be said about the wall deposition of the spray dryer. Due to the increases in residence time of the wall deposition powder exposing them to prolonged heat, the Maillard reaction that is happening on the powder kept advancing and thus producing melanoidins that cause the darkening of the powder and rougher texture.[23] The worst scenario happened on the powder that sticks in the head of the spray dryer. Since the powder is kept exposed to high heat from the hot air inlet, the powder experience thermal degradation and scorched the powder resulting in a dark color with a very rough texture.

Spray Dryer Efficiency

The efficiency of the spray dryer has been calculated using the data presented on Table 1. Efficiency based on the total powder yield produced by the spray dryer is presented in Table 2.

It is shown from Table 2 that by increasing the inlet air temperature from 200 °C to 230 °C, powder yield of the spray dryer is increased. The increase of powder yield with regards to inlet air temperature shows that thermal degradation that can reduce powder yield of *biancaea sappan* extract has not happened.[24]

Table 2. Efficiency of the spray dryer with 150 grams of total solid (maltodextrin) in 1 liter of *biancaea sappan* extract solution.

Temperature (°C)	Efficiency (%)
200	48,4
230	53,8

While some losses can be attributed to unrecovered wall deposition, a significant chunk of the loss is most likely occurs from the fine particles that is leaving through the cyclone outlet carried by the exhaust air.[25] To combat this problem, the introduction of bag filters to filter out the fine particles that escape from the cyclone.[26] However, the fine particles that are captured by the bag filters would be unusable since fine particles suffers from poor flowability and reconstitution behavior.[27] Another way to dealing this problem could be exhaust air that carries fine particles can be recirculated back into the drying chamber to promote agglomeration of the particles resulting in heavier particles and better quality powder.[28]

CONCLUSION

An experimental investigation of a spray dryer prototype has been conducted. Maximum evaporation rate of the spray dryer was achieved at 750 mL/h for inlet temperature of 200 °C and 1000 mL/h for inlet temperature of 230 °C with both results achieved with an air pressure of 4 bar and 30 L/min airflow rate due to a finer droplet of particles resulting in better mass heat transfer increasing evaporation capacity. An increase of evaporation capacity also occurs when inlet air temperature was raised.

[23] Yingying Li et al., "Review of Melanoidins as By-Product from Thermal Hydrolysis of Sludge: Properties, Hazards, and Removal," *Processes* 12, no. 1 (2024): 135, https://doi.org/10.3390/pr12010135.

[24] Yuting Tao et al., "Effects of Spray Drying Temperature on Physicochemical Properties of Grapeseed Oil Microcapsules and the Encapsulation Efficiency of Pterostilbene," *LWT* 193 (2024): 115779, https://doi.org/10.1016/j.lwt.2024.115779.

[25] Patricija Čulina et al., "Optimization of the Spray-Drying Encapsulation of Sea Buckthorn Berry Oil," *Foods* 12, no. 13 (2023): 2448, https://doi.org/10.1111/jfpe.14059.

[26] Nik Farhan Nazmi Nik Abd Rahman et al., "Revolutionizing Spray Drying: An In-Depth Analysis of Surface Stickiness Trends and the Role of Physicochemical Innovations in Boosting Productivity," *Journal of Food Quality* 2024, no. 1 (2024): 8929464, https://doi.org/10.1155/2024/8929464.

[27] Anneloes P van Boven et al., "Investigation on Nozzle Zone Agglomeration during Spray Drying Using Response Surface Methodology," *Powder Technology* 429 (2023): 118910, https://doi.org/10.1016/j.powtec.2023.118910.

[28] Jakob Alfons Fröhlich, Nora Alina Ruprecht, and Reinhard Kohlus, "Nozzle Zone Agglomeration in Spray Dryers: Determination of the Agglomeration Efficiency in the Fines Return by Means of Agglomerate Properties and Residence Time Distribution," *Drying Technology* 41, no. 12 (2023): 1907–23, https://doi.org/10.1080/07373937.2023.2203224.

Yield of the spray dryer increased from increasing inlet air temperature from 200 °C to 230 °C due to greater amount of moisture removal from the increase of temperature. A significant amount of wall deposition was found on the head of spray dryer that could be caused by recirculation. The bottom of the drying chamber and the floor of the cyclone duct also has an excessive amount of wall deposition which could be caused by particle stickiness, lack of atomization or the lack of airflow velocity of the system.

Due to Maillard reaction, the higher the heat experienced by the particle the quicker it will darken due to accelerated Maillard reaction. Exposing particles to prolonged heat will also darken the color of the particles and cause a rougher texture.

With a yield efficiency of 48.4% and 53.8% at inlet temperature of 200 °C and 230 °C respectively, a significant amount of loss is likely caused by fine particles leaving the cyclone carried by the exhaust air. This problem could be remedied by bag filters or recirculation of exhaust air into the drying chamber.

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DECLARATION OF CONFLICTING INTERESTS

The authors state that there is no conflict of interest in the publication of this article.

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