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Drying of stingless bees pot-pollen using swirling fluidized bed dryer

Luqman Abdul Halim[a], Firdaus Basrawi[a], Ahmmad Shukrie Md Yudin[a], Amir Abdul Razak[a], Nor Azfa Johari[b], Azira Muhamad[b], and Mohd Razif Mamat[b]

[a]Meliponini Engineering Laboratory (MePEL), Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, Pekan, Pahang, Malaysia; [b]Department of Translational Research and Prototype Development, Malaysia Genome Institute (MGI), National Institute of Biotechnology Malaysia (NIBM), Kajang, Selangor Darul Ehsan, Malaysia

ABSTRACT

High moisture content in stingless bees pot-pollen makes preservation difficult. Since pot-pollen is heat sensitive, using conventional drying techniques below 40 °C is time consuming. A fluidized bed dryer (FBD) with swirling distributor is proposed for rapid drying of the pot-pollen while conserving the nutrients. The objectives of this study are to investigate the possibility of using swirling FBD to dry pot-pollen, and to investigate the effect of distributor type and superficial air velocity on pot-pollen drying. Stingless bees pot-pollen from the state of Pahang, Malaysia was dried at different conditions. Three distributor types: perforated, 45° inclination angle, and 67° inclination angle were tested at three superficial air velocities of 1.0 m/s, 1.5 m/s, and 2.0 m/s. Then, moisture content before and after drying were studied. To ensure swirling FBD would preserve the nutrition content of pot-pollen, nuclear magnetic resonance (NMR) analysis on the pot-pollen before and after drying was also carried out. It was found that at higher velocity, the drying rate increased. The 67° swirling distributor has the best drying performance, followed by the 45° swirling and perforated distributor. The highest reduction in moisture content, 13.5% in this study was found when using 67° distributor at 2.0 m/s. This translates to a drying rate of 0.450%/min, about 6.2 times faster than conventional FBD, 5.6 times faster drying rate compared to hot air dryer (HAD) at 45 °C, 44.5 times higher than oven drying at 30 °C, and also a staggering 225 times quicker than cyclic convective dryer (CCD). It is also comparable to lower power levels of microwave assisted vacuum dryer (MW-VD), without damaging pot-pollen nutrients. The NMR analysis showed no adverse effect due to drying. Hence, it is possible to dry pot-pollen rapidly using swirling FBD without damaging its nutrition content, and using the 67° swirling distributor is preferred.

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Drying; stingless bees; pollen; fluidized bed

1. Introduction

A vital pollination agent for the tropical forest, stingless bees are usually reared for their honey.[1] The pollen collected by these native bees are then blended with nectar and bee enzymes and stored in cerumen pots inside their nests.[2] These stored pollen is called bee bread or pot-pollen, the latter term is exclusive to stingless bees species.[3] Pot-pollen are loaded with nutrients, such as proteins, carbohydrates, lipids, vitamins, phenolic compounds and essential amino acids.[4–6] Additionally, pot-pollen have medicinal and therapeutic benefits, exhibiting antibiotic and antimicrobial properties[7,8] and a suitable chemo-preventive agent for cancer treatment.[9] Besides, they also showed to have valuable phenolic content that exhibits high antioxidant activity.[10,11]

Difficulty in preserving raw pot-pollen rendered them as waste by the beekeepers. This problem arises due to elevated moisture content in raw pot-pollen, which can lead to excessive fermentation and spoilage. In general, stingless bees pot-pollen has higher moisture content level compared to honey bees bee bread. Some of reported moisture content values for stingless bees pot-pollen and honey bees bee bread are illustrated in Figure 1. For pot-pollen, the moisture content usually exceeds 20% and can even reach as high as 46%.[3,12–15] On the other hand, bee bread from honey bees in general has lower moisture content compared to stingless bees pot-pollen; where some reported value range are around 7.4% to 16.6%[16–19] However, the moisture content level may be affected by factors such as humidity, seasonality, and floral composition.[10,11]

CONTACT Firdaus Basrawi mfirdausb@ump.edu.my Meliponini Engineering Laboratory (MePEL), Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang, Pekan, Pahang 26600, Malaysia.

Thus, appropriate drying methods are necessary to reduce the moisture content down to suitable levels. Conventional methods, namely sun-drying, infrared drying, and sublimation drying have unfavorable effects to the pot-pollen, causing loss of bioactive compounds, caramelization and also nutrient loss.[20] In most drying applications, temperature is the major parameter that dictates the drying rate. Drying rates can be seen to increase as temperature increased.[21–25] However, for pollen materials, elevated temperature may negatively affect their nutrients. Caramelization will start to occur at drying temperature of around 55 °C.[26] It is also reported that higher temperature treatment of around 40 °C to 45 °C can alter and produce unpleasant aroma.[27] Excessive heating can also lead to antioxidants be depleted.[28,29] Thus, due to the heat sensitive nature of pollen material, drying is advised to be kept at low temperature to retain its nutrients.[30] Limited heating up to 40 °C can ensure the nutrition and quality be retained.

There is no rapid drying study below 40 °C reported. Thus, fluidized bed dryer (FBD) is a potential technique as they have homogeneous and rapid drying, making it a suitable candidate for drying of heat sensitive materials.[31] However, there has been no research reported on FBD for pot-pollen.

For heat-sensitive materials, other parameters need to be explored to increase the drying performance of FBD such as the velocity of the fluidizing air. Superficial air velocities generally have positive correlation toward drying rate in FBD. This happens as the superficial air velocities rise, more heat and mass transfer will occur throughout the bed.[23,32–34] Thus, controlling the fluidizing air velocity may enable drying rate of the bed material in FBD to be improved. However, study on the effect of velocity on the drying performance and nutrient of stingless bees pot-pollen is unknown.

Apart from velocity, drying rate may also be increased by improving the fluidizing air flow such as adding swirling flow. Swirling airflow in FBD produced by several means such as by using swirling twisted tape or axial vane swirl generator has been shown to accelerate drying rate compared to conventional FBD.[35,36] In terms of particle mixing and circulation rate, Yudin et al. found that inclined slot swirling distributor at 45° angle is better compared to perforated and 90° angle.[37] In fluidized bed combustion (FBC), 67° swirling distributor is attributed for lower pressure drop and enhanced particle mixing in contrast to conventional distributor designs.[38] However, it is not known whether the study can also

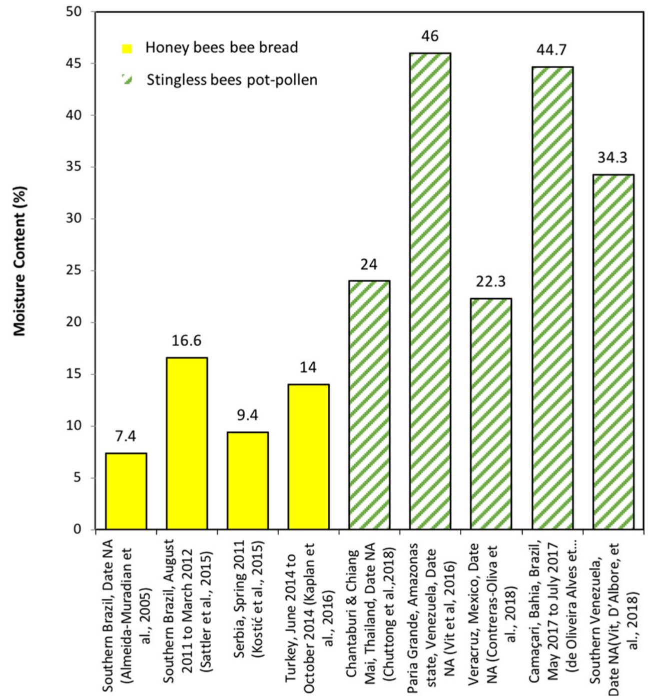

Figure 1. Moisture content level of honey bees bee bread and stingless bees pot-pollen from different species of bees according to different authors, various regions of the world, and different seasons of the year.

be applicable to improve drying rates of particulate materials.

From the literature reviewed, no study is currently reported on the possibility to dry pot-pollen by FBD without damaging its nutritional contents, and the effect of distributor and velocity on fluidized bed drying of stingless bees pot-pollen is also unknown. Hence, the objectives of this study are to investigate the possibility of using swirling FBD to dry pot-pollen, and to investigate the effect of distributor type, and superficial air velocity on pot-pollen drying. Thus, a sample of pot-pollen from Pahang was collected and dried using different distributor types and at different velocities. Then, moisture content before and after drying was compared, and drying rate investigated. Finally, NMR analysis for the sample before and after drying was investigated to ensure drying does not affect pot-pollen nutritional value.

2. Materials and methods

2.1. Sample preparation

The stingless bees pot-pollen sample was collected from a local farm in Kuantan, Pahang, Malaysia, with coordinates 3°47′10.55″ (N), 103°14′4.44″ (E), and acquired in November 2018 from hives of *Heterotrigona itama* species. The raw pot-pollen acquired was thoroughly cleaned

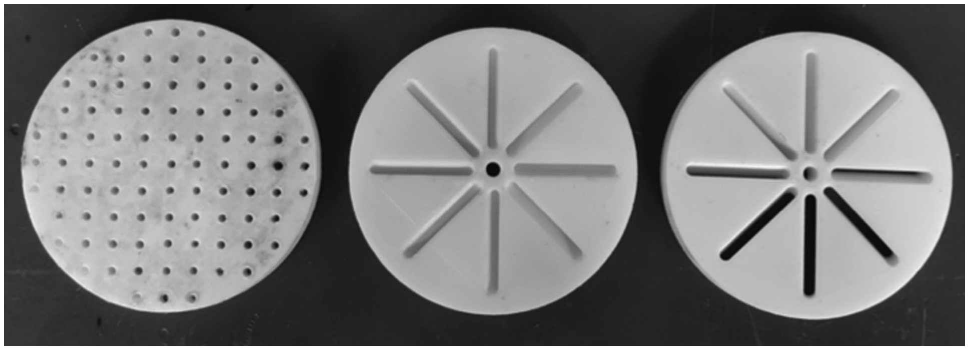

Figure 2. From left to right, perforated distributor, 45° swirling distributor, and 67° swirling distributor.

and kept at −10 °C storage. Prior to drying experiment, the raw pot-pollen was crushed lightly using a pestle and mortar, and the initial moisture content was analyzed.

2.2. Determination of moisture content

To obtain the moisture content level of raw and dried pot-pollen samples, a thermogravimetric method was utilized. Moisture content of raw and dried samples were determined, with the samples heated in a laboratory oven (MTI Corporation DZF-6050) at 100 °C until constant weight. The moisture content was then calculated using the following equation:

$$\text{Moisture Content, MC }(\%) = \frac{w_i - w_f}{w_i} \times 100\% \quad (1)$$

where w_i and w_f are initial and final weights [g], respectively.

2.3. Distributor designs

Three different distributors used in this study are shown in Figure 2. All distributors have similar diameter of 110 mm. The perforated distributor consists of 89 round holes with diameter of 3 mm arranged in square pitch with distance of 10 mm. The 45° swirling distributor and 67° swirling distributor consist of inclined slot at 45° and 67° angles, respectively.

2.4. Drying experiment

A lab-scale fluidized bed dryer was used for the drying experiment. The setup consists of (1) an air blower that provides fluidizing air at ambient temperature conditions, (2) a valve to control the superficial air velocity, (3) a removable air distributor, (4) a drying chamber to contain the sample, and (5) a fine filter to prevent escape of finer particles.

A perforated distributor was used and inserted in a slot immediately under the drying chamber. The control valve was adjusted such that the superficial air velocity inside the drying chamber was set at 1.0 m/s, measured using a hot wire anemometer (Lutron YK-2400AH). Then, 50 g of raw pot-pollen was weighed and put inside the drying chamber.

The drying experiment was conducted for 30 minutes. The steps were repeated with velocities at 1.5 m/s and 2.0 m/s, and with 45° swirling distributor and 67° swirling distributor. The drying experiments were performed in triplicates. The final moisture content of each dried sample was then determined. From the moisture content value, the rate of moisture removal can then be determined using the equation as follows:

$$\text{Drying rate, } \eta_D \ (\%/\text{min}) = \frac{\Delta MC}{t} \quad (2)$$

where ΔMC is change in percentage moisture content [%], and t is total drying time [min].

2.5. Pot-pollen metabolite profiling

In order to ensure little or no alteration to the nutrients of pot-pollen a further analysis was needed. This was to verify that the drying method used did not negatively affect the pot-pollen. Raw pot-pollen sample and pot-pollen sample dried with 67° swirling distributor and at 2.0 m/s was then subjected to analysis using nuclear magnetic resonance (NMR) to obtain pot-pollen metabolite profiles.

For NMR analysis, 0.5 g samples were diluted in 1 mL ultrapure water and incubated for 1 hour with shaking. NMR buffer were mixed with samples and subjected to analysis. The NMR spectra readings produced were recorded at 300 K on a Bruker Ascend 700 MHz spectrometer.

3. Results and discussion

3.1. Final moisture content and drying rate

Figure 3 shows the moisture content level of pot-pollen samples after the drying experiment for 30 minutes with different distributor types at superficial air velocities of (a) 1.0 m/s, (b) 1.5 m/s, and (c) 2.0 m/s, respectively. The initial moisture content level of raw pot-pollen was determined to be 30.5%. This value was within typical range for stingless bees pot-pollen.[16–19]

It can be seen that the 67° swirling distributor has superior drying performance across all three velocities tested, followed by 45° swirling distributor, and perforated distributor. The 67° swirling distributor managed to reduce the moisture content as much as 12%, 12.5%, and 13.5% at superficial air velocities of 1.0 m/s, 1.5 m/s, and 2.0 m/s, respectively. On the other hand, the 45° swirling distributor performed better than the perforated distributor, with 0.5% more reduction for all velocities tested. The swirling distributor performance can be attributed to higher mass and heat transfer due to enhanced air flow inside the drying chamber especially with the 67° swirling distributor. The airflow direction can be observed in Figure 4. Circulation of pot-pollen particle and mixing is most vigorous using 67° swirling distributor, followed by 45° swirling distributor and perforated distributor. Thus, in terms of distributor types tested, the 67° swirling distributor is preferred for better drying performance in stingless bees pot-pollen drying.

There is a positive effect of superficial air velocity toward drying rate, where increasing the velocity leads to lower final moisture content level. This shows that the drying rate is faster at elevated velocities. This is caused by higher mass and heat transfer due to faster flow inside the drying chamber. This is consistent with previous studies found on drying of other food materials. The drying time is shortened when air velocity is increased in fluidized bed drying of kaffir lime leaves,[34] carrot slices,[39] rice,[40] and green peppers.[32] Hence, higher velocity is recommended for enhance drying rate.

Figure 5 shows the drying rates of various drying techniques for bee pollen reported in literature and compared to the present study. Vizcarra-Mendoza et al. reported drying of lower moisture content bee pollen using conventional FBD at 55 °C and 2.0 m/s. Kanar and Mazı studied the drying of Turkey bee pollen using microwave-assisted vacuum drying (MW-VD) at several power levels.[41] Barajas et al. reported Colombia bee pollen drying using hot air dryer (HAD) at 45 °C.[42] Combey carried out drying using oven kept at 30 °C.[43] Kashirin et al. proposed a cyclic convective dryer (CCD) for honey bees bee bread.[44] The drying rates are relative comparisons as opposed to directly comparing drying methods for similar bee pollen materials that are difficult. This is due to variations of samples collected due to several factors such as original humidity, floral composition, seasonality and age of the samples collected and studied.

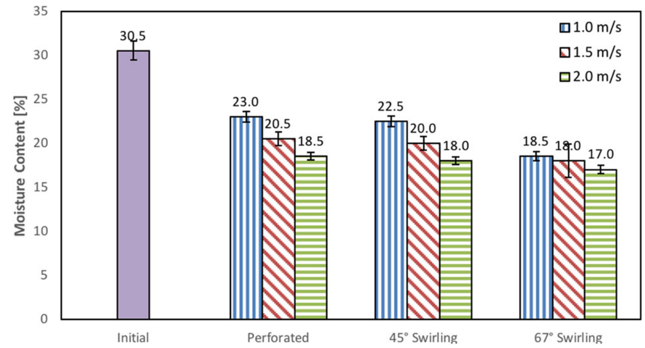

Figure 3. Moisture content level of raw and pot-pollen dried with perforated, 45° swirling and 67° swirling distributor at superficial air velocities of 1.0 m/s, 1.5 m/s, and 2.0 m/s (Pot-pollen samples were collected from a local farm in Kuantan, Pahang, Malaysia, with coordinates 3°47′10.55″ (N), 103°14′4.44″ (E), and acquired in November 2018 from hives of *Heterotrigona itama* species).

From the various drying methods listed, the highest drying rate, which is at 2.00%/min was reported when drying in MW-VD at 900 W power level. This exceptionally high drying rate, is about 5 times higher as compared to the present study. In other studies, microwave assisted fluidized bed drying (MFBD) have also shown to drastically improve drying rate of food materials such as soybean, cumin, and ginger.[45–47] However, the downside of MFBD includes difficulty to control the drying temperature, as well as degradation of the bed material especially for food products which are typically heat sensitive.[48] Thus, high power level of microwave would negatively affect the composition of bee pollen. Hence, Kanar and Mazi recommended MW-VD to be applied at lower power levels to minimize the adverse effect on dried material. At the lowest power level tested, which is at 300 W, MW-VD has a drying rate of 0.406%/min This is comparable to the FBD with 67° swirling distributor used in the present study, where the drying rates were found to be 0.400%/min, 0.417%/min, and 0.450%/min, at velocities of 1.0 m/s, 1.5 m/s, and 2.0 m/s, respectively. All conditions tested in this study also have higher drying rates when compared to conventional FBD, HAD, oven drying, and CCD. Drying of stingless bees pot-pollen in FBD with 67° swirling distributor at 2.0 m/s is about 6.2 times faster than conventional FBD, 5.6 times faster drying rate compared to HAD at 45 °C, 44.5 times higher than oven drying at 30 °C, and also a staggering 225 times quicker than CCD. In essence, FBD with swirling distributor has the most rapid drying rate, second only to higher levels of MW-VD.

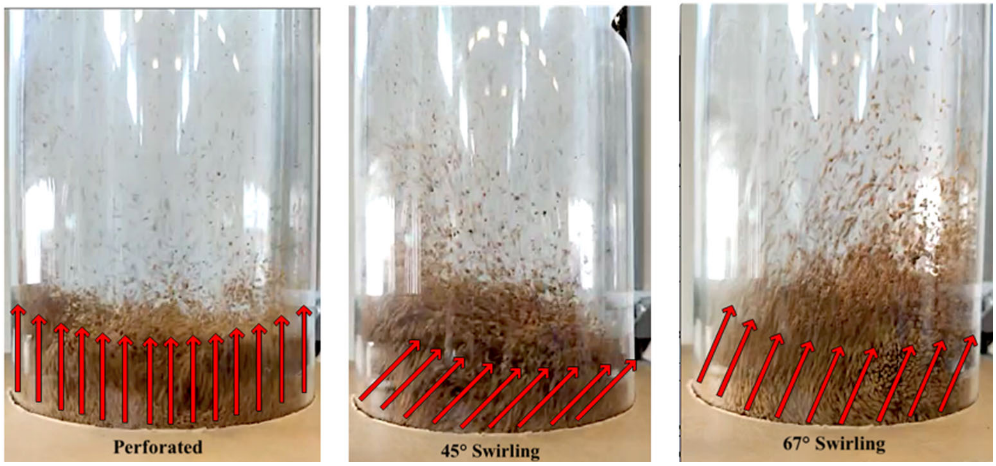

Figure 4. Pot-pollen in drying chamber when using (from left to right), a perforated distributor, 45° swirling distributor, and 67° swirling distributor.

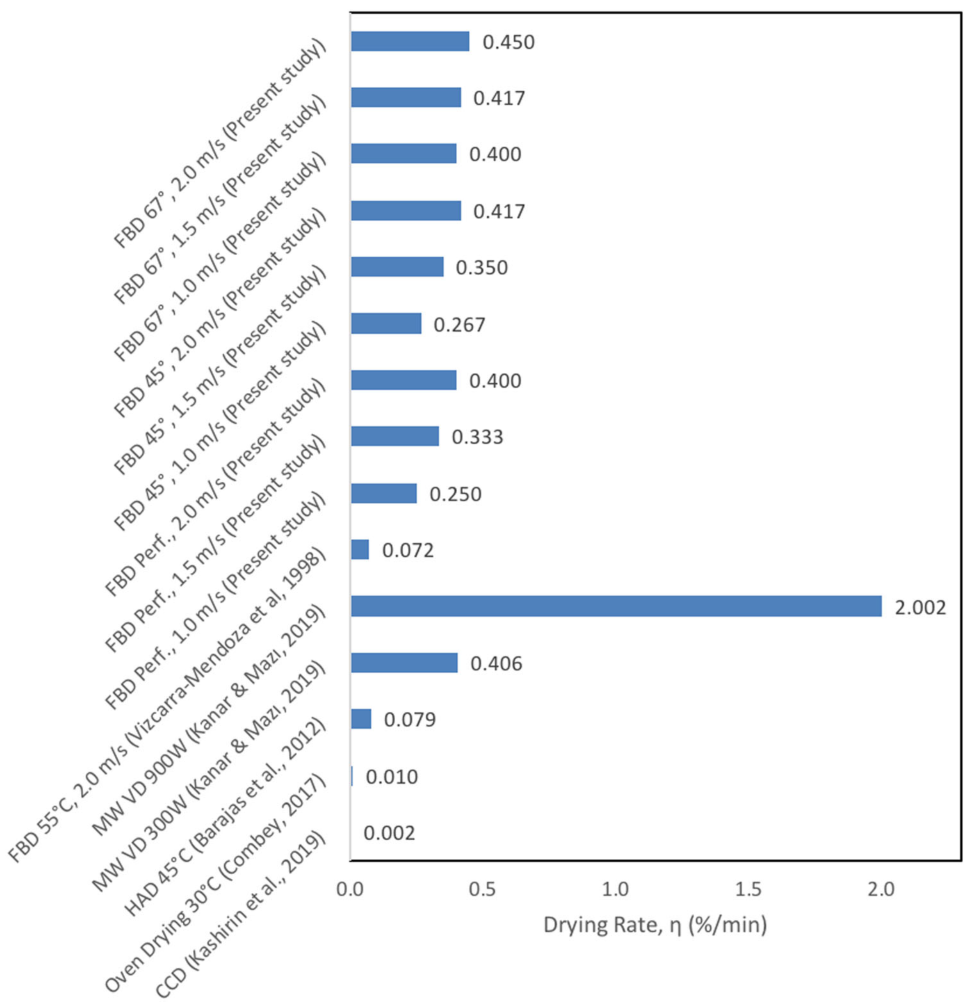

Figure 5. Relative comparison of drying rates in the present study with other drying methods for pollen materials.

3.2. Pot-pollen metabolite profiling

Figure 6 shows the overall NMR spectra of pot-pollen profile, comparing raw unprocessed pot-pollen and dried pot-pollen, represented by red and blue, respectively. The overall profile is similar for both raw and dried stingless bees pot-pollen. This indicates that the fluidized bed drying with swirling distributor had not negatively impact the pot-pollen nutrient.

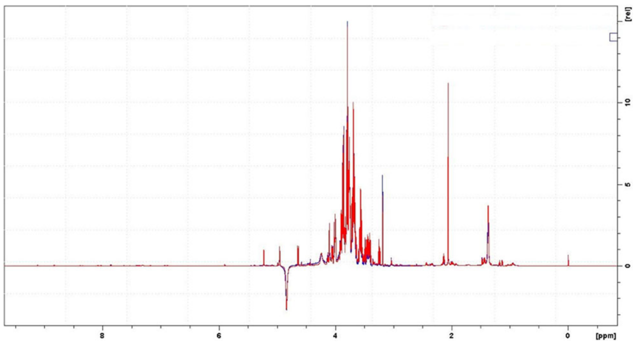

Figure 6. Overlay of overall pot-pollen spectra before (red) and after (blue) drying process (Pot-pollen samples were collected from a local farm in Kuantan, Pahang, Malaysia, with coordinates 3°47′10.55″ (N), 103°14′4.44″ (E), and acquired in November 2018 from hives of *Heterotrigona itama* species).

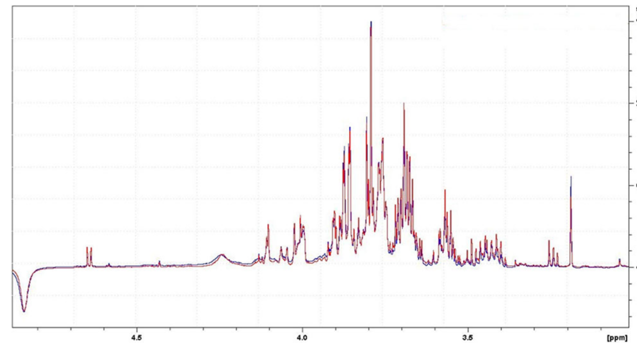

Figure 7. Overlay of pot-pollen sugar region spectra before (red) and after (blue) drying process (Pot-pollen samples were collected from a local farm in Kuantan, Pahang, Malaysia, with coordinates 3°47′10.55″ (N), 103°14′4.44″ (E), and acquired in November 2018 from hives of *Heterotrigona itama* species).

A close up view of the sugar profile region can be seen in Figure 7. Similar to the overall profile, the sugar region has not deteriorated. Instead, only a slight increase in concentration of the compounds in sugar region can be observed when compared to raw pot-pollen samples.

Based on the NMR analysis, there are no significant differences between similar compounds detected in both raw and dried pot-pollen samples. However, small changes can be observed in compounds concentration where most compounds in pot-pollen sample were found to increase in concentration after the drying process. Thus, from the NMR analysis of stingless bees pot-pollen profile, drying in fluidized bed dryer with swirling distributor does not negatively affect the compounds present in pot-pollen.

4. Conclusion

The possibility of drying of stingless bees pot-pollen in fluidized bed dryer and the drying performance using perforated, 45° swirling, and 67° swirling distributors and at superficial air velocities of 1.0 m/s, 1.5 m/s, and 2.0 m/s were investigated. It was found that 67° swirling distributor had the best drying performance across all velocities studied, followed by 45° swirling distributor and perforated distributor. The positive effect of superficial air velocity on drying performance managed to increase the drying rates when the velocities were increased for all distributor types tested. The highest moisture reduction of 13.5% was obtained using the 67° swirling distributor at 2.0 m/s, equivalent to 0.450%/min drying rate. This is superior to other drying techniques for pollen material, except for high power levels of MW-VD. However, high power levels of MW-VD were found to be damaging to the nutritional content. In addition, NMR analysis showed that fluidized bed drying using swirling distributor did not have adverse effect on compounds in pot-pollen, with minimal increase in concentration of most compounds. Therefore, it is possible to rapidly dry pot-pollen without adverse effect on the compound with swirling FBD. In addition, fluidized bed drying with 67° swirling distributor at higher velocity is recommended for drying stingless bees pot-pollen, as it has the most rapid and efficient drying performance without negative impact to its nutrients.

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ORCID

Amir Abdul Razak http://orcid.org/0000-0001-5479-7025

References

[1] Azmi, W. A.; Zulqurnain, N. S.; Ghazi, R. Melissopalynology and Foraging Activity of Stingless Bees, *Lepidotrigona terminata* (Hymenoptera: Apidae) from an Apiary in Besut, Terengganu. *J. Sustain. Sci. Manag.* **2015**, *10*, 27–35.

[2] Halim, L. A.; Basrawi, F.; Chong, J. Z.; Oumer, A. N.; Yudin, A. S. M.; Bin Yusof, M. H.; Sulaiman, S. A. Preliminary Study on Drying of Stingless Bee Pot Pollen Using Novel Fluidized Bed Dryer with Swirling Distributor. *MATEC Web Conf.* **2018**, *225*, 04007. DOI: 10.1051/matecconf/201822504007.

[3] Vit, P.; D'Albore, G. R.; Barth, O. M.; Peña-Vera, M.; Pérez-Pérez, E. Characterization of Pot-Pollen from Southern Venezuela. In *Pot-Pollen in Stingless Bee Melittology*, 1st ed.; Vit, P., Pedro, S. R. M.,

Roubik, D. W., Eds.; Springer International Publishing: Cham, **2018**; pp 361–375.

[4] Nagai, T.; Nagashima, T.; Suzuki, N.; Inoue, R. Antioxidant Activity and Angiotensin I-Converting Enzyme Inhibition by Enzymatic Hydrolysates from Bee Bread. *Z. Naturforsch. C J. Biosci.* **2005**, *60*, 133–138. DOI: 10.1515/znc-2005-1-224.

[5] Feas, X.; Vazquez-Tato, M. P.; Estevinho, L.; Seijas, J. A.; Iglesias, A. Organic Bee Pollen: Botanical Origin, Nutritional Value, Bioactive Compounds, Antioxidant Activity and Microbiological Quality. *Molecules* **2012**, *17*, 8359–8377. DOI: 10.3390/molecules17078359.

[6] Urcan, A. C.; Al Marghitas, L.; Dezmirean, D. S.; Bobis, O.; Bonta, V.; Muresan, C. I.; Margaoan, R. Chemical Composition and Biological Activities of Beebread—Review. *Bull. UASVM Anim. Sci. Biotechnol.* **2017**, *74*, 6–14. DOI: 10.15835/buasvmcn-asb:12646.

[7] Abouda, Z.; Zerdani, I.; Kalalou, I.; Faid, M.; Ahami, M. T. The Antibacterial Activity of Moroccan Bee Bread and Bee-Pollen (Fresh and Dried) against Pathogenic Bacteria. *Res. J. Microbiol.* **2011**, *6*, 376–384. DOI: 10.3923/jm.2011.376.384.

[8] Akhir, R. A. M.; Bakar, M. F. A.; S. B. Sanusi, Antioxidant and Antimicrobial Activity of Stingless Bee Bread and Propolis Extracts. AIP Conference Proceedings, Kedah, Malaysia, **2017**, vol. 1891. DOI: 10.1063/1.5005423.

[9] Omar, W. A. W.; Azhar, N. A.; Fadzilah, N. H.; Kamal, N. N. S. N. M. Bee Pollen Extract of Malaysian Stingless Bee Enhances the Effect of Cisplatin on Breast Cancer Cell Lines. *Asian Pac. J. Trop. Biomed.* **2016**, *6*, 265–269. DOI: 10.1016/j.apjtb.2015.12.011.

[10] Duarte, A. W. F.; Vasconcelos, M. R. D. S.; Oda-Souza, M.; De Oliveira, F. F.; López, A. M. Q. Honey and Bee Pollen Produced by Meliponini (Apidae) in Alagoas, Brazil: Multivariate Analysis of Physicochemical and Antioxidant Profiles. *Food Sci. Technol.* **2018**, *38*, 493–503. DOI: 10.1590/fst.09317.

[11] Vasconcelos, M. R. d. S.; Duarte, A. W. F.; Gomes, E. P.; da Silva, S. C.; López, A. M. Q. Physicochemical Composition and Antioxidant Potential of Bee Pollen from Different Botanical Sources in Alagoas, Brazil. *Ciênc. Agrotec.* **2017**, *41*, 447–458. DOI: 10.1590/1413-70542017414009317.

[12] Chuttong, B.; Phongphisutthinant, R.; Sringarm, K.; Burgett, M.; Barth, O. M. Nutritional Composition of Pot-Pollen from Four Species of Stingless Bees (Meliponini) in Southeast Asia. In *Pot-Pollen in Stingless Bee Melittology*, 1st ed.; Vit, P., Pedro, S. R. M., Roubik, D. W., Eds.; Springer International Publishing: Cham, **2018**; pp 313–324.

[13] Patricia, V.; Bertha, S.; Pedro, S. R. M.; Ruíz, J.; Maza, F.; María, P. V.; Elizabeth, P. P. Chemical and Bioactive Characterization of Pot-Pollen Produced by *Melipona* and *Scaptotrigona* Stingless Bees from Paria Grande, Amazonas State, Venezuela. *Emir. J. Food Agric.* **2016**, *28*, 78–84. DOI: 10.9755/ejfa.2015-05-245.

[14] Contreras-Oliva, A.; Pérez-Sato, J. A.; Gómez-Merino, F. C.; López-Garay, L. A.; Villanueva-Gutiérrez, R.; Crosby-Galván, M. M.; Trejo-Téllez, L. I. Characterization of Scaptotrigona Mexicana Pot-Pollen from Veracruz, Mexico. In *Pot-Pollen in Stingless Bee Melittology*, 1st ed.; Vit, P., Pedro, S. R. M., Roubik, D. W., Eds.; Springer International Publishing: Cham, **2018**; pp 325–337.

[15] de Oliveira Alves, R. M.; da Silva Sodré, G.; Carvalho, C. A. L. Chemical, Microbiological, and Palynological Composition of the 'Samburá' Melipona Scutellaris Pot-Pollen. In *Pot-Pollen in Stingless Bee Melittology*, Vit, P., Pedro, S. R. M., Roubik, D. W., Eds.; Springer International Publishing: Cham, **2018**; pp 349–360.

[16] Almeida-Muradian, L. B.; Pamplona, L. C.; Coimbra, S.; Barth, O. M. Chemical Composition and Botanical Evaluation of Dried Bee Pollen Pellets. *J. Food Compos. Anal.* **2005**, *18*, 105–111. DOI: 10.1016/j.jfca.2003.10.008.

[17] Sattler, J. A. G.; de Melo, I. L. P.; Granato, D.; Araújo, E.; da Silva de Freitas, A.; Barth, O. M.; Sattler, A.; de Almeida-Muradian, L. B. Impact of Origin on Bioactive Compounds and Nutritional Composition of Bee Pollen from Southern Brazil: A Screening Study. *Food Res. Int.* **2015**, *77*, 82–91. DOI: 10.1016/j.foodres.2015.09.013.

[18] Kostić, A. T.; Barać, M. B.; Stanojević, S. P.; Milojković-Opsenica, D. M.; Tešić, ŽL.; Šikoparija, B.; Radišić, P.; Prentović, M.; Pešić, M. B. Physicochemical Composition and Techno-Functional Properties of Bee Pollen Collected in Serbia. *LWT - Food Sci. Technol.* **2015**, *62*, 301–309. DOI: 10.1016/j.lwt.2015.01.031.

[19] Kaplan, M.; Karaoglu, Ö.; Eroglu, N.; Silici, S. Fatty Acid and Proximate Composition of Bee Bread. *Food Technol. Biotechnol.* **2016**, *54*, 497–504. DOI: 10.17113/ftb.54.04.16.4635.

[20] Akhmetova, R.; Sibgatullin, J.; Garmonov, S.; Akhmetova, L. Technology for Extraction of Bee-Bread from the Honeycomb. *Procedia Eng.* **2012**, *42*, 1822–1825. DOI: 10.1016/j.proeng.2012.07.577.

[21] Goksu, E. I.; Sumnu, G.; Esin, A. Effect of Microwave on Fluidized Bed Drying of Macaroni Beads. *J. Food Eng.* **2005**, *66*, 463–468. DOI: 10.1016/j.jfoodeng.2004.04.017.

[22] Srinivas, G.; Setty, Y. P. Drying Behavior of Uniform and Binary Mixture of Solids in a Batch Fluidized Bed Dryer. *Powder Technol.* **2013**, *241*, 181–187. DOI: 10.1016/j.powtec.2013.03.023.

[23] Taghavivand, M.; Choi, K.; Zhang, L. Investigation on Drying Kinetics and Tribocharging Behaviour of Pharmaceutical Granules in a Fluidized Bed Dryer. *Powder Technol.* **2017**, *316*, 171–180. DOI: 10.1016/j.powtec.2016.10.061.

[24] Meziane, S. Drying Kinetics of Olive Pomace in a Fluidized Bed Dryer. *Energy Convers. Manag.* **2011**, *52*, 1644–1649. DOI: 10.1016/j.enconman.2010.10.027.

[25] Arumuganathan, T.; Manikantan, M. R.; Rai, R. D.; Anandakumar, S.; Khare, V. Mathematical Modeling of Drying Kinetics of Milky Mushroom in a Fluidized Bed Dryer. *Int. Agrophysics* **2009**, *23*, 1–7.

[26] Vizcarra-Mendoza, M. G.; Ruiz-Martinez, R. S.; Martinez-Vera, C.; Iruegas-Evaristo, A.; Carrillo-

Guerreno, J. M. Treatment of Pollen by Fluidization. *Dry. Technol.* **1998**, *16*, 1843–1853. DOI: 10.1080/07373939808917499.

[27] Collin, S.; Vanhavre, T.; Bodart, E.; Bouseta, A. Heat Treatment of Pollens: Impact on Their Volatile Flavor Constituents. *J. Agric. Food Chem.* **1995**, *43*, 444–448. DOI: 10.1021/jf00050a035.

[28] Nurdianah, H. F.; Firdaus, A. H. A.; Azam, O. E.; Adnan, W. O. W. Antioxidant Activity of Bee Pollen Ethanolic Extracts from Malaysian Stingless Bee Measured Using DPPH-HPLC Assay. *Int. Food Res. J.* **2016**, *23*, 403–405.

[29] Pascoal, A.; Rodrigues, S.; Teixeira, A.; Feás, X.; Estevinho, L. M. Biological Activities of Commercial Bee Pollens: Antimicrobial, Antimutagenic, Antioxidant and anti-Inflammatory. *Food Chem. Toxicol.* **2014**, *63*, 233–239. DOI: 10.1016/j.fct.2013.11.010.

[30] Song, X. D.; Mujumdar, A. S.; Law, C. L.; Fang, X. M.; Peng, W. J.; Deng, L. Z.; Wang, J.; Xiao, H. W. Effect of Drying Air Temperature on Drying Kinetics, Color, Carotenoid Content, Antioxidant Capacity and Oxidation of Fat for Lotus Pollen. *Dry. Technol.* **2019**, *0*, 1–14. DOI: 10.1080/07373937.2019.1616752.

[31] Mujumdar, A. S. *Handbook of Industrial Drying*, 4th ed.; CRC Press: Boca Raton, **2014**.

[32] Chuwattanakul, V.; Banthumporn, K.; Promvonge, P.; Eiamsa-Ard, S. Drying Peppercorn Characteristics in Fluidized Bed Dryer Equipped with Baffle Vortex Generators. *IOP Conf. Ser. Earth Environ. Sci.* **2018**, *136*, 012020. DOI: 10.1088/1755-1315/136/1/012020.

[33] Perazzini, H.; Freire, F. B.; Freire, J. T. The Influence of Vibrational Acceleration on Drying Kinetics in Vibro-Fluidized Bed. *Chem. Eng. Process. Process Intensif.* **2017**, *118*, 124–130. doi: . DOI: 10.1016/j.cep.2017.04.009.

[34] Tasirin, S. M.; Puspasari, I.; Lun, A. W.; Chai, P. V.; Lee, W. T. Drying of Kaffir Lime Leaves in a Fluidized Bed Dryer with Inert Particles: Kinetics and Quality Determination. *Ind. Crops Prod.* **2014**, *61*, 193–201. DOI: 10.1016/j.indcrop.2014.07.004.

[35] Chuwattanakul, V.; Eiamsa-Ard, S. Hydrodynamics Investigation of Pepper Drying in a Swirling Fluidized Bed Dryer with Multiple-Group Twisted Tape Swirl Generators. *Case Stud. Therm. Eng.* **2019**, *13*, 100389. DOI: 10.1016/j.csite.2018.100389.

[36] Özbey, M.; Söylemez, M. S. Effect of Swirling Flow on Fluidized Bed Drying of Wheat Grains. *Energy Convers. Manag.* **2005**, *46*, 1495–1512. DOI: 10.1016/j.enconman.2004.08.005.

[37] Yudin, A. S. M.; Anuar, S.; Oumer, A. N. Improvement on Particulate Mixing through Inclined Slotted Swirling Distributor in a Fluidized Bed: An Experimental Study. *Adv. Powder Technol.* **2016**, *27*, 2102–2111. DOI: 10.1016/j.apt.2016.07.023.

[38] Yudin, A. S. M. Performance Characteristics of Air Distributor Designs in a Fluidized Bed. Ph.D Dissertation, Fac. of Mech. Eng, Universiti Malaysia Pahang, Malaysia, **2017**.

[39] Reyes, A.; Alvarez, P. I.; Marquardt, F. H. Drying of Carrots in a Fluidized Bed. I. Effects of Drying Conditions and Modelling. *Dry. Technol.* **2002**, *20*, 1463–1483. DOI: 10.1081/DRT-120005862.

[40] Thant, P. P.; Robi, P. S.; Mahanta, P. Inclined Fluidized Bed Dryer Performance in Energy Saving Option. *Int. J. Sci. Eng. Technol. Res.* **2018**, *7*, 230–237.

[41] Kanar, Y.; Mazı, B. G. HMF Formation, Diastase Activity and Proline Content Changes in Bee Pollen Dried by Different Drying Methods. *LWT - Food Sci. Technol.* **2019**, *113*, 108273. DOI: 10.1016/j.lwt.2019.108273.

[42] Barajas, J.; Cortes-Rodriguez, M.; Rodríguez-Sandoval, E. Effect of Temperature on the Drying Process of Bee Pollen from Two Zones of Colombia. *J. Food Process Eng.* **2012**, *35*, 134–148. DOI: 10.1111/j.1745-4530.2010.00577.x.

[43] Combey, R. Microbial and Qualitative Analyses of Stingless Bee Bread Using Dry Preservation Methods. *Euro J Zool Res.* **2017**, *5*, 45–50.

[44] Kashirin, D. E.; Uspensky, I. A.; Kostenko, M. Y.; Rembalovich, G. K.; Danilov, K. I.; Kokorev, G. D.; Byshov, D. N.; Makarov, V. A.; Nefedov, B. A.; Tsymbal, A. A.; Ulyanov, V. M. Cyclic Convective Drying of Bee Pollen. *ARPN J. Eng. Appl. Sci.* **2019**, *14*, 916–920.

[45] Anand, A.; Gareipy, Y.; Raghavan, V. Fluidized Bed and Microwave-Assisted Fluidized Bed Drying of Seed Grade Soybean. *Dry. Technol.* **2020**, 1–21. DOI: 10.1080/07373937.2019.1709495.

[46] Uddin, Z.; Suppakul, P.; Boonsupthip, W. Effect of Air Temperature and Velocity on Moisture Diffusivity in Relation to Physical and Sensory Quality of Dried Pumpkin Seeds. *Dry. Technol.* **2016**, *34*, 1423–1433. DOI: 10.1080/07373937.2015.1119840.

[47] Babaki, A.; Askari, G.; Emam-Djomeh, Z. Drying Behavior, Diffusion Modeling, and Energy Consumption Optimization of Cuminum Cyminum L. undergoing Microwave-Assisted Fluidized Bed Drying. *Dry. Technol.* **2020**, *38*, 224–234. DOI: 10.1080/07373937.2019.1652638.

[48] Lv, W.; Li, S.; Han, Q.; Zhao, Y.; Wu, H. Study of the Drying Process of Ginger *(Zingiber officinale* Roscoe) Slices in Microwave Fluidized Bed Dryer. *Dry. Technol.* **2016**, *34*, 1690–1699. DOI: 10.1080/07373937.2015.1137932.