Food Chemistry Advances 3 (2023) 100392

Contents lists available at ScienceDirect

Food Chemistry Advances

journal homepage: www.elsevier.com/locate/focha

Effect of spray drying parameters on the physicochemical properties and oxidative stability of oil from menhaden (*Brevoortia* spp.) and Asian swamp eel (*Monopterus albus*) oil extract microcapsules

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ARTICLE INFO

Keywords:
Monopterus albus
Brevoortia spp
Fish oil
Spray drying
Inlet air temperature
Feed flow rate
Oxidative stability

ABSTRACT

This work investigated the effect of spray drying parameters on the physicochemical properties and oxidative stability of oil from menhaden (*Brevoortia* spp.) and Asian swamp eel (*Monopterus albus)* oil microcapsules. Different emulsion formulations (Maltodextrin - MD, Maltodextrin+Gum Arabic - MD+GA, and Maltodextrin+Starch - *M*+*S*), inlet air temperatures (180, 190, and 200 °C), and feed flow rates (280, 382, and 485 mL/h) were applied to microencapsulate *Brevoortia* spp. oil. The best operating parameters were then used to microencapsulate the *Monopterus albus* oil. The moisture content, MC (%), peroxide value, PV (mEq/kg), free fatty acid, FFA (%), acid value, AV (mg KOH/g) and the morphology of the microcapsules were then evaluated. The *Brevoortia* spp. oil microcapsules produced with the Maltodextrin+Gum Arabic emulsion formulation, inlet air temperature of 200 °C, and feed flow rate of 280 mL/h showed the lowest moisture content, peroxide value, free fatty acid, and acid value of 9.145%, 3.293 mEq/kg, 4.891%, and 2.981 mg KOH/g, respectively. Using similar parameters, the microencapsulation of the *Monopterus albus* oil extract recorded a moisture content, peroxide value, free fatty acid, and acid value of 8.432%, 2.713 mEq/kg, 4.911%, and 2.871 mg KOH/g, respectively. In conclusion, improved physicochemical properties and oxidative stability of *Monopterus albus* oil extract microcapsules were achieved using the Maltodextrin+Gum Arabic emulsion formulation and spray drying at a high air inlet temperature of 200 °C and a low feed flow rate of 280 mL/h.

Introduction

Fish oil is a well-known source of long-chain omega-3 polyunsaturated fatty acids (PUFAs), which are mainly composed of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Apart from their potential application to replace anti-inflammatory medicines to treat occupational dermatitis (OCD), EPA and DHA are related to various neuronal functions and are beneficial in treating psoriasis and its adverse effects (Amin et al., 2018; Chen et al., 2020). The primary sources of omega-3 fatty acids include seawater fish, such as mackerel (*Scombridae* spp.), herring (*Clupea harengus*), tuna (*Thunnus*), and salmon (*Salmo salar*) (Hashim et al., 2021) and various freshwater fish, such as swamp eel fish (*Monopterus albus)* (Saylor et al., 2021). The *Monopterus albus* is associated with several health advantages due to its high levels of EPA, DHA, and vitamins, such as A, B1, B2, B12, D, and E, all of which are essential for the body's overall health (Razak et al., 2001; Venugopalan et al., 2021).

Despite the health advantages of fish oil, one of the primary challenges in producing fish oil-based goods is the consistent supply of fresh and reliable fish oil throughout the manufacturing and storage period. It is known that oxidised PUFAs results in fish oil with an unpleasant taste, poor qualities, and shortened shelf life (Ramos et al., 2021). Hence, it is necessary to stabilise fish oil during handling, processing, and storage. Microencapsulation is an alternative approach for enhancing the

Abbreviations: AV, acid value, mg koh/g; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; FFA, free fatty acid,%; GA, gum arabic; MC, moisture content, %; Md, maltodextrin; PUFA, Polyunsaturated Fatty Acid; PV, Peroxide Value, mEq/kg; OCD, Occupational Dermatitis; S, Starch; SEM, Scanning Electron Microscope.

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https://doi.org/10.1016/j.focha.2023.100392
Received 12 November 2022; Received in revised form 15 July 2023; Accepted 16 July 2023
Available online 17 July 2023

oxidative stability of fish oil, extending its shelf life, and enabling its distribution without altering its flavour (Barrow et al., 2013; Eucina et al., 2018). Additionally, the method can aid the isolation, protection, transport, and release of elementary nutrients required for good health, such as PUFAs (Bakry et al., 2016). Furthermore, microencapsulation is suitable to leather the undesirable taste and smell of fish oil-based products and improve their sensory appeal to meet consumer satisfaction (Mohammed et al., 2020).

Spray drying is considered the most common encapsulation technique besides freeze drying, coacervation, and extrusion (Abdul Mudalip et al., 2021; Kralovec et al., 2012). However, spray drying requires a high inlet temperature of up to 215 °C, which may lead to the thermal deterioration of the extracts and produce a poor-quality powdered product (Gallo et al., 2015). This issue can be overcome using an emulsifier and wall material to encapsulate the targeted product with suitable process parameters, such as inlet drying temperature and feed flow rate (Shamaei et al., 2017). According to Gharsallaoui et al. (2007), fish oil-based goods can be encapsulated using emulsifiers and carrier agents that exhibit specific properties, including low viscosity, high water solubility, and able to form a protective film around the product. Additionally, they must be capable of producing stable emulsions prior to the spray drying process (Tabatabaei et al., 2022). For example, maltodextrin (MD), a partly hydrolysed starch derivative with the capacity to form film, is frequently used to encapsulate foods, pharmaceuticals, and essential oil products during the spray drying process (Rahmani-Manglano et al., 2022).

Besides MD, starches (S) and gum arabic (GA) are extensively utilised as wall materials to encapsulate flavours and oils due to their excellent emulsification and film-forming characteristics (Selvia Fardhyanti et al., 2022). Previous research has investigated the microencapsulation processes and the effect of different wall materials on the microencapsulation of various fish oils (Łozińska et al., 2020; Ramos et al., 2021). Although MD is mainly utilised as the wall material, it should be mixed with an emulsifier to improve its quality (Abdel-Wahhab et al., 2021). As such, there has not been any report on the influence of a binary mix of MD and GA or S, as well as the parameters of the spray drying process on the physicochemical qualities and oxidative stability of *Brevoortia* spp. oil and *Monopterus albus* oil extract. Therefore, this work was carried out to assess the use of the spray drying technique and the potential utilisation of mixed emulsion formulation to microencapsulate *Brevoortia* spp. oil and *Monopterus albus* oil extract.

Materials and methods

Chemical and materials

Fish oil from menhaden (*Brevoortia* spp.) CAS 8002–50–4 (Merck, Germany) and fresh *Monopterus albus* purchased from the local market (Kuantan, Pahang, Malaysia) were the main materials in this study. The components for the wall materials include maltodextrin DE 10.9 (MD), gum arabic (GA), and tapioca starch (S), which were supplied by R&M Chemical (Malaysia), Merck (Germany), and Thye Huat Chan (Malaysia), respectively. Analytical grade ethanol 95% (Wt), methanol 98% (Wt), and n-hexane were obtained from Merck (Germany). The deionised water produced by Milli-Q (Millipore) water purification system was used to prepare emulsions. In addition, analytical grade ammonium thiocyanate (NH_4SCN), barium chloride 2-hydrate ($BaCl_2{\cdot}2H_2O$), anhydrous iron (II) chloride ($FeCl_2$), iron powder, sodium hydroxide (KOH) pellets, analytical grade n-butanol, and hydrochloric acid (HCl) 37% (Wt) used for the peroxide value analysis were supplied by R&M Chemical (Malaysia). All chemicals and materials were used without further purification.

Extraction of monopterus albus oil

The ATC-FO 300 Microwave (Milestone, Germany) was used to extract *Monopterus albus* oil following the method described by Hashim et al. (2022). The *Monopterus albus* was first cut to obtain the fillet. The head, internal parts and bones were removed. The fillet was cut into smaller pieces, washed to remove access blood. The fillet was then oven-dried for 15 h at 70 °C to remove moisture, ground, and finally sieved to obtain a uniform size powder. For the crude oil extraction, 10 g of the *Monopterus albus* powder was mixed with 75 mL of ethanol and shaken to allow consistent expansion. The mixture was placed in the laboratory microwave at 800 W and 60 °C for 30 min, and the crude oil extract was collected in an amber bottle for each batch. Subsequently, the collected crude extract was filtered using Whatman No. 1 filter to remove particulates prior to solvent/oil separation using a rotary evaporator, Rotavapor R-100 (Buchi, Switzerland). The water bath and condenser were set at 70 °C and 20 °C, respectively. Finally, the *Monopterus albus oil* extract was stored at 4 °C until further use.

Emulsion preparation

The emulsion preparation method reported by Tirgar et al. (2015) was referred in this study with minor adjustments. The aqueous phase was prepared by dispersing 24% (Wt) MD in 100 mL of deionised water and stirring at 700 rpm for 20 h under room temperature conditions. Next, 6% (Wt) of *Brevoortia* spp. oil was gradually added to the solution. The mixture was homogenised for 5 min at 20,000 rpm using a high-shear homogeniser (IKA, Germany). The homogenised emulsion was immediately used for the spray drying process. Around 400 mL of the emulsion was freshly prepared for every microcapsule batch. The same emulsion preparation procedure was repeated using 19% (Wt) MD and 5% (Wt) of emulsifiers (GA or S).

Microencapsulation using spray drying

The *Brevoortia* spp. oil and *Monopterus albus* oil extract were microencapsulated using a SD-06A lab-scale spray dryer (Lab Plant, United Kingdom) with a 0.5 mm double fluid jet nozzle. The feed and air supply tubes were connected to the jet nozzle assembly, and compressed air pressure was set to a maximum of 2 bar. The feed flow rate, inlet air temperature, and air-dry flow rate were set to 382 mL/h, 190 °C, and 2.7 m/s, respectively. The resulting spray-dried microcapsules were collected in sealed amber glass bottles and stored at room temperature conditions with silica gel to retain their moisture content until further analysis. The same spray drying procedure was repeated using different emulsion formulations, inlet air temperature, and feed flow rate provided in supplementary materials, Table S1. The best operating parameters obtained from the *Brevoortia* spp. oil microcapsules were then applied for the *Monopterus albus* oil extract microencapsulation.

Characterisation and analysis

Moisture content

The Moisture Content (MC) percentage of the spray-dried *Brevoortia* spp. oil and *Monopterus albus* oil extract were determined using an MS-70 moisture analyser (A&D, Japan) with a readability of ± 0.0001%. Approximately 2 g of the sample was placed on the measuring pan and heated to 105 °C. The MC (%) was recorded once a constant weight was attained. All samples were subjected to the same protocols in triplicates.

Peroxide value

The Peroxide Value (PV) was determined based on the standard method described by the International Dairy Federation (IDF) and Lavanya et al. (2019) with slight modifications. Primarily, 3 g of powdered sample was added into a tube containing 15 mL of hexane and vortexed for 3 min. The mixture was centrifuged at 3500 rpm for 60 min to separate the oil from the wall material. The precipitate was discarded, and excess hexane in the collected supernatant was evaporated overnight at room temperature in the fume hood. The obtained oil was

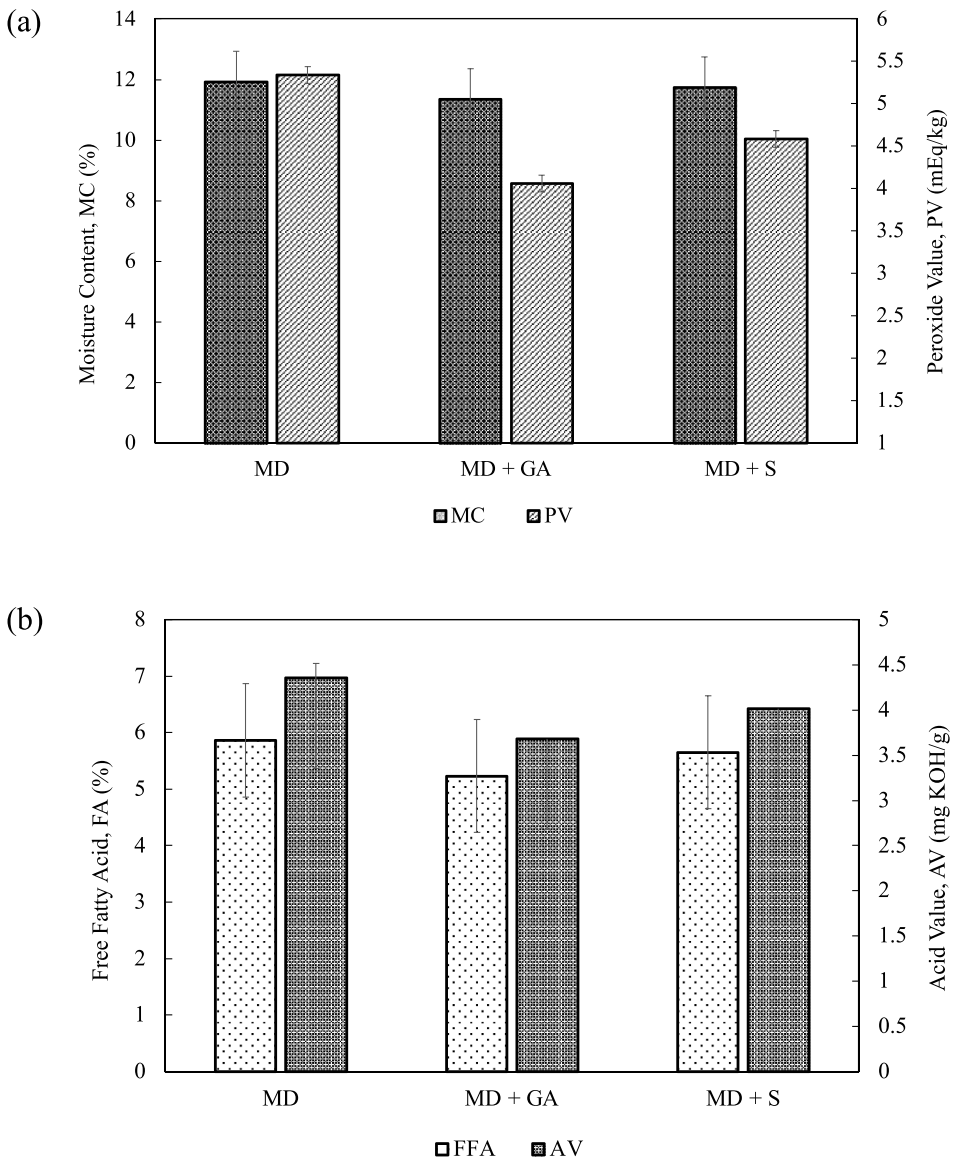

Fig. 1. The effect of the MD, MD+GA, and MD+S emulsion formulation on (a) MC and PV and (b) FFA and AV of the microencapsulated Brevoortia spp. oil. The inlet temperature, air dry flow, and feed flow rate were set to 190 °C, 2.7 m/s, and 382 mL/h, respectively. Results are expressed as the mean ± standard deviation.

determined gravimetrically and stored in a chiller at 4 °C until further use. Afterwards, approximately 2 mg of the collected oil was mixed with 3 mL of working solvent (methanol:butanol at a 2:1 v/v ratio) and vortexed until completely dissolved. Then, 15 µL of prepared NH_4SCN was added and vortexed for 5 s. For magenta colour formation, 15 µL of $FeCl_2$ was added and vortexed. The mixture was then incubated for 20 min in the dark at room temperature. Ultimately, the absorbance value of the mixture was measured using a GENESYS 50 UV–Vis Spectrophotometer (Thermo Scientific, United Kingdom) at a wavelength of 517 nm. For the calibration curve, the working solvent was used as the blank to produce mixtures containing iron powder with a concentration range of 2–14µg/mL. The collected absorbance values were used to construct a calibration curve. Eq. (1) was used to calculate the PV:

$$Peroxide\ Value,\ PV\ (mEq/kg) = \frac{(As - Ab)m}{(55.84) \times\ m0\ \times\ 2} \quad (1)$$

where *As* refers to the absorbance value of the sample, *Ab* represents the absorbance value of the blank, *m* indicates the slope of the Fe (III) standard curve, *m0* denotes the mass of the sample (g), and 55.84 is the atomic weight of Fe (III) (Lavanya et al., 2019). The PV of the microcapsule was expressed in milliequivalents of active oxygen per kilogram of oil (mEq/kg). The same procedures were repeated using all samples and measured in triplicate.

Free fatty acid and acid value

The Free Fatty Acid value (FFA) and Acid Value (AV) was measured using a 785 DMP Titrino automatic titrator (Metrohm, Herisau, Switzerland). The titration solvent was prepared by dissolving 3 g of KOH in 1 L of absolute ethanol to obtain 0.1 mol/L KOH in an ethanol titrant. Then, 2 g of the microencapsulated *Brevoortia* spp. oil was added into a beaker containing 30 mL of absolute ethanol and stirred for 10 min. Once the potentiometric sensor was immersed in the solution, the FFA and AV were collected based on the measured titration curve displayed by the automatic titrator. The same procedure was repeated for

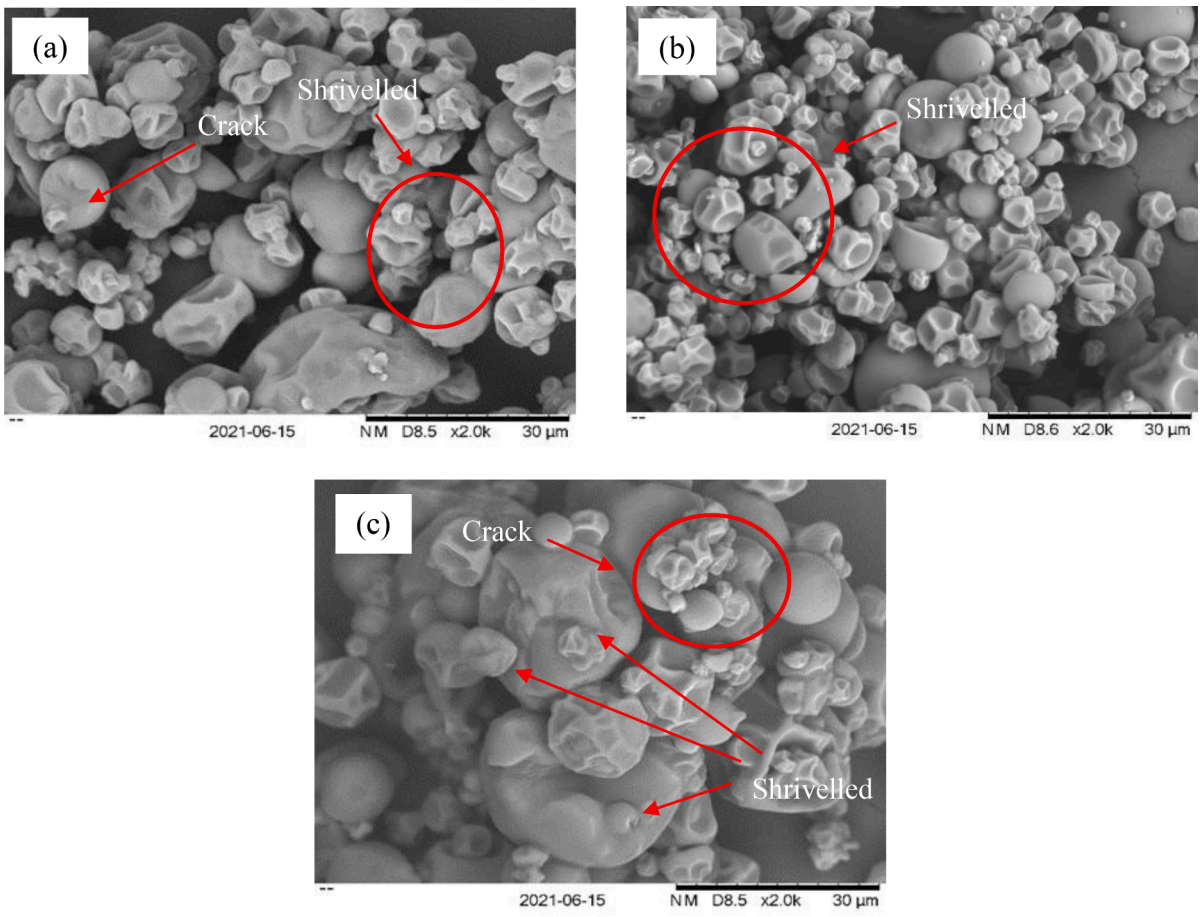

Fig. 2. The SEM images of the microencapsulated Brevoortia spp. oil based on (a) MD, (b) MD+GA, and (c) MD+S formulations at 2000x magnification.

all samples and measured in triplicate.

Powder surface morphology

The morphological structure of the microencapsulated powder was analysed using a TM2020 Plus Scanning Electron Microscope (SEM) (Hitachi Hight-Technologies Corporation, Japan). The sample was placed on double-sided adhesive carbon tabs and gold-coated with Q300TD (Quorum Technologies, United Kingdom) before being analysed at an accelerating voltage of 15.0 kV and magnified up to 2000x (Charles et al., 2016).

Statistical analysis

Statistical analyses were performed using a Microsoft Excel 2022 data analysis tools pack (version 16.69.1) software. All reported data represent the average of triplicate analysis, expressed as THE mean ± standard deviation. The Analysis of Variance (ANOVA) was also applied to assess the differences between factor means and considered statistically significant at $p < 0.05$.

Results and discussion

Effect of emulsion formulation

Fig. 1(a) and 1(b) show the effect of the varying emulsion formulations on the MC, PV, FFA, and AV of the microencapsulated *Brevoortia* spp. oil. The recorded MC for the MD+GA microcapsules was slightly lower than those with only MD and MD+*S* as the wall material. However, the PV, FFA, and AV varied significantly. The lowest MC, PV, FFA, and AV of 11.321 ± 0.010%, 4.061 ± 0.028 mEq/kg, 5.231 ± 0.042, and 3.678 ± 0.023 mg KOH/g, respectively, were recorded by the MD+GA microcapsules with significant differences ($p < 0.05$) compared to the MD and MD+*S* microcapsules. It can be inferred that the incorporation of GA and S into the wall material formulation may have contributed to the varying characteristics of the microcapsules. In addition, the low MC in the MD+*S* or MD+GA microcapsules was consistent with the results by Charles et al. (2021), which reported lower MC for fish oil microcapsules made with a combined MD and agarwood starch or whey protein formulation. According to Klinkesorn et al. (2006), the MC should be lower than 4% for dry powdered food products. On the contrary, a high MC value may cause the release of core material or oil during storage, increasing the lipid oxidation of oil in the microcapsule (Velasco et al., 2009).

The MD+GA or MD+*S* formulations also reduced the PVs, FFAs, and AVs. PV represents the oxidation of fish oil microcapsules, where a lower PV indicates lower oxidative degradation of the oil. A low AV and FFA also demonstrate more stable oil capsules due to the reduced hydrolytic rancidity and hydrolysis. Typically, the hydrolysis of triglycerides in fish oil, either by heat, microbial, or enzymatic activities, increases rancidity, which becomes the primary substrate of lipid oxidation (Riaz & Rokey, 2012). Afolabi et al. (2018) stated that AV of less than 8 mg KOH/g is still within a permissible range. Nevertheless, the AVs obtained in this work are higher than that suggested by Codex Standard for Fish Oils Rep 15/FO Appendix III Ismail et al. (2016) and the United States Pharmacopeia intended for human consumption, which stated that the AV value should be equivalent to or less than 3 mg KOH/g. The acceptable amount of PV was set at 10 mEq/kg oil based on the guidelines provided by the British Pharmacopeia Fish Oil Type I and the EU Pharmacopeia Fish Oil Type I (De Boer et al., 2018).

Changes in the PVs, FFAs, and AVs resulting from adding GA or S to

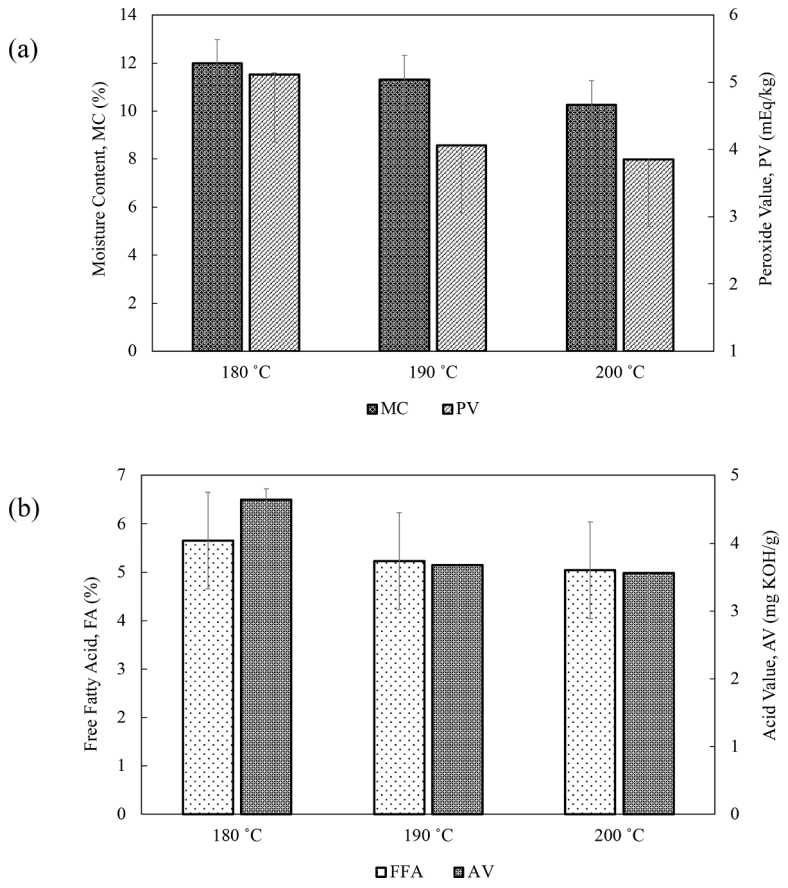

Fig. 3. The effect of inlet air temperatures at 180, 190, and 200 °C on (a) MC and PV and (b) FFA and AV of the microencapsulated Brevoortia spp. oil. The MD+GA was used as the emulsion formulation, and the feed flow rate was 382 mL/h. Results are expressed as the mean ± standard deviation.

MD during the emulsion preparation demonstrated the compounds' potential to enhance the poor emulsifying capacity of MD and, in turn, impact the coating and preservation of the core material from oxidative degradation. It was reported that starch is a low-cost hydrocolloid that serves as an effective oxygen barrier and has a high capacity to form a matrix but exhibits a low viscosity even when present in an emulsion with a high solid content (Sartori & Menegalli, 2016). Other works by Liu et al. (2017) and Premi & Sharma (2017) also stated that the MD used for emulsion preparation prior to the spray drying process is more advantageous when mixed with GA since GA can act as a film-forming, moisture-stabilising agent, and can stabilise bacterial cells during the drying process and storage. However, using GA alone in the emulsion formulation is not recommended due to its high cost (Lekshmi et al., 2021). Interestingly, the MD+GA formulation achieved the lowest MC, PV, FFA, and AV in the present study, indicating a higher quality of fish oil microcapsules. Nevertheless, further research is required to reduce the microcapsules' MC and AV by less than 4% and 3 mg KOH/g, respectively.

Fig. 2 depicts the SEM micrographs of the MD, MD+GA, and MD+*S* microcapsules at 2000x magnification. Regardless of the wall material composition, the microcapsules showed a relatively spherical shape with varied diameters, which is a typical characteristic of spray-dried powders. In addition, the morphology of the MD+GA and MD+*S* microcapsules displayed less structural irregularity than those produced with MD alone. For example, Fig. 2(b) depicts that the MD+GA microcapsules had a relatively smooth surface with no visible cracks and minimal shrinking. According to Alcântara et al. (2019), this behaviour indicates that the wall material completely covered the core material. Conversely, the morphology of the MD+S microcapsules in Fig. 2(c) reveals numerous irregular-shaped and cracked microcapsules. This is probably due to the decreased film development during atomised droplet drying. According to BÖGer et al. (2018), the irregular-shaped and cracked microcapsules severely impact the flow characteristics and may increase the surface area of the powder, contributing to the rapid oxidation of the core material. These findings are consistent with the PV of MD and MD+*S* microcapsules, which are higher than that of the MD+AG microcapsules.

Effect of inlet air temperature

Fig. 3(a) illustrates the MC and PV of the microencapsulated *Brevoortia* spp. oil at different inlet air temperatures. According to the result, the MC and PV decreased with the increase in the inlet air temperature. The lowest MC of 10.254 ± 0.044% and PV of 3.8554 ± 0.011 mEq/kg were obtained at an inlet air temperature of 200 °C with significant differences ($p < 0.05$). It could be explained that higher inlet air temperatures induce a greater driving force, resulting in faster heat transmission inside atomised droplets. This phenomenon may enhance the rate of water evaporation, lowering the overall MC. Similar findings were reported for other spray-drying food products, such as açai (Euterpe oleraceae Mart.) and orange (*Citrus sinensis* L.) essential oil microcapsules (Ren et al., 2020; Tonon et al., 2008). The result also aligns with the report by Aghbashlo et al. (2012), who described that the moisture evaporation and mass transfer rate accelerated when the inlet air temperature was elevated, leading to lower MC of the microcapsules yet high PV. Such conditions occurred due to the greater tendency of oil to generate peroxides that induce rapid oxidation at higher temperatures. In this study, the wall materials employed during emulsion preparation may have provided an adequate protective barrier to the core material and reduced the fish oil oxidation at elevated

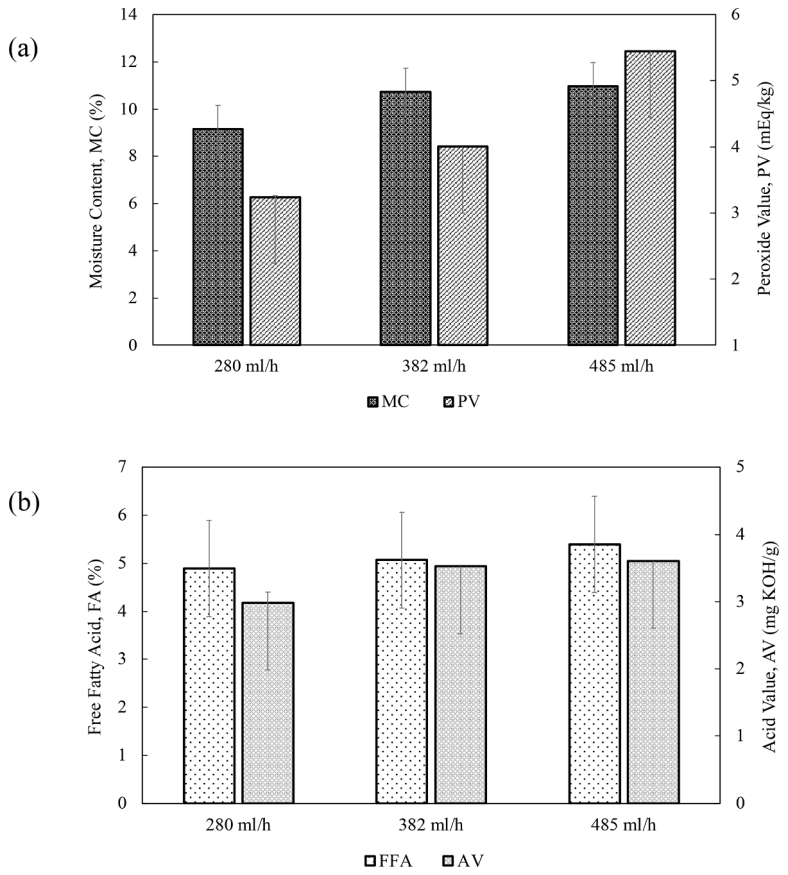

Fig. 4. The effect of the feed flow rate of 280, 382, and 485 mL/h on (a) MC and PV and (b) FFA and AV of the microencapsulated Brevoortia spp. oil. The MD+GA was used as the emulsion formulation, and the inlet air temperature was 200 °C. Results are expressed as the mean ± standard deviation.

temperatures.

Fig. 3(b) illustrates the FFA and AV of the varying microcapsules at different inlet air temperatures. The FFAs and AVs generally depict a decreasing trend with the increase in inlet air temperatures from 180 to 200 °C. The lowest FFA of 5.041 ± 0.021% and AV of 3.557 ± 0.004 mg KOH/g were recorded at an inlet temperature of 200 °C. The decreasing trend of FFAs and AVs at higher inlet air temperatures indicates fewer oils and fats hydrolysis in the microcapsuled samples. It could also be associated with a low MC since MC is directly related to powder stability (Mehrad et al., 2015). Thus, the inlet air temperature of 200 °C was the best parameter for minimising the MC, PV, FFA, and AV.

Effect of feed flow rate

The MC, PV, FFA, and AV of the *Brevoortia* spp. oil microcapsules obtained at different feed flow rates are illustrated in Fig. 4(a) and (b). The MC, PV, FFA, and AV rose as the feed flow rate increased from 280 to 485 mL/h. The lowest MC (9.145 ± 0.047%), PV (3.239 ± 0.002 mEq/kg), FFA (4.891 ± 0.093%), and AV (2.981 ± 0.121 mg KOH/g) were recorded at the lowest feed flow rate of 280 mL/h. The sufficient contact time between fish oil emulsion and drying air at a low feed flow rate resulted in efficient heat transfer and an increased rate of water evaporation, leading to the lowest MC. These findings support the work by Tonon et al. (2008), who studied the impact of feed flow rate on the physicochemical properties of *E. oleraceae* Mart. powder. A higher feed flow rate implies a shorter contact time between the emulsion and drying air, affecting the heat transfer efficiency and decreasing water evaporation. Meanwhile, Fig. 4(b) shows the effect of the feed flow rate on the FFA and AV. The elevated FFA and AV contents may be due to the production of fatty acids from the hydrolysis of triglyceride molecules, which was influenced by the varying feed flow rates. In short, the feed

Table 1
Physicochemical properties of the microencapsulated Monopterus albus oil extract produced using the spray drying technique under the best operating parameters. Results are expressed as the mean ± standard deviation.

Analysis	*Monopterus albus oil* extract
Moisture Content, MC (%)	8.432 ± 0.001
Peroxide Value, PV (mEq/kg)	2.713 ± 0.013
Free Fatty Acid, FFA (%)	4.911 ± 0.151
Acid Value, AV (mg KOH/g)	2.871 ± 0.004

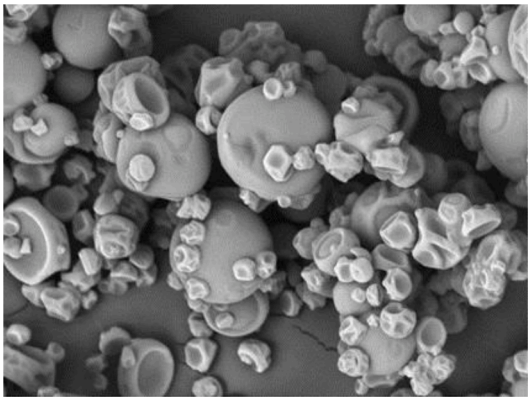

Fig. 5. The SEM image of Monopterus albus oil extract microcapsules using the MD+GA emulsion formulation produced at an inlet air temperature of 200 °C and feed flow rate of 280 mL/h (2000x magnification).

flow rate of 280 mL/h recorded an AV of lower than 3 mg (KOH/g), while the feed flow rates of 382 mL/h and 485 mL/h exceeded the Codex Standard of Fish Oil. Nevertheless, the recorded AV remained within the acceptable limit based on the United States Pharmacopeia.

Monopterus albus oil extract microcapsules

The best operating parameters for spray drying *Brevoortia* spp. oil were applied to microencapsulate the *Monopterus albus* oil extract. Table 1 shows the MC, PV, FFA, and AV of the microencapsulated *Monopterus* albus oil extract. The MC and PV were 8.432 ± 0.001% and 2.713 ± 0.013 mEq/kg, respectively, lower than those of the *Brevoortia* spp. oil. However, the FFA and AV were 4.911 ± 0.151% and 2.871 ± 0.004 mg KOH/g, respectively. Therefore, a low FFA and AV indicate a higher microcapsule quality. The findings from the microencapsulated *Brevoortia* spp. oil and *Monopterus albus* oil extract were compared with previous findings and tabulated in supplementary materials, Table S2.

Fig. 5 illustrates the morphological images of the microencapsulated *Monopterus albus* oil extract at 2000x magnification. The size and shape of the microspheres appeared significantly different, which is typical for spray-dried microcapsules. Besides, the dented structure on the particle's surface was observed without any visible cracks and fissures, implying lower permeability to gases, which is desirable for adequately protecting the essential fish oil content against oxidation (Lavanya et al., 2019). Thus, the MD+GA emulsion formulation and the applied spray drying parameters of 200 °C inlet air temperature and feed flow rate of 280 mL/h were demonstrated as the best approach for the microencapsulation of *Monopterus albus* oil extract.

Conclusion and prospects

This study successfully employed a spray drying technique to microencapsulate *Brevoortia* spp. oil and *Monopterus albus* oil extract. Apart from the MD+GA emulsion formulation, the high air inlet temperature of 200 °C and low feed flow rate of 280 mL/h was the best operating spray drying parameters to achieve microcapsules with improved physicochemical properties and oxidative stability. Furthermore, the morphological imaging of the spray-dried *Brevoortia* spp. oil and *Monopterus albus* oil extract microcapsules showed smooth particle surfaces due to the lower MC and PV. Although the proposed spray drying technique demonstrates excellent physicochemical properties and oxidative stability of the *Brevoortia* spp. oil and *Monopterus albus* oil extract, the microencapsulation is only effective under certain conditions. Failure to control the process would lead to further oil oxidation. Other process parameters, such as the air-dry flow rate and emulsion ratios, should be included in future research. The study on the microcapsule storage condition should also be addressed to optimise the microcapsules' properties and prolong their shelf life. It is also recommended for future research to study the potential use of industrial wastes as a wall material component, which would significantly minimise the production cost and enhance the microcapsules' quality.

Author statement

This manuscript was prepared and written from our original research work at Universiti Malaysia Pahang with no financial interest to report and is not under review at any other publication. The contribution of each author is as follows:

Nurmaryam Aini Hashim: Original draft (lead), investigation, data acquisition and interpretation; Muhammad Fitri Azizi Mohd Norzi: Original draft, investigation, data acquisition; Zatul Iffah Mohd Arshad: Introductory and encapsulation method; Nurul Aini Mohd Azman: Analysis of moisture content and discussion; and Siti Kholijah Abdul Mudalip: Conceptualisation (lead), review and final editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgment

The authors appreciate the financial support from the Ministry of Education Malaysia through the Fundamental Research Grant Scheme FRGS/1/2019/K02/UMP/02/9 (Grant No. RDU1901134) and Universiti Malaysia Pahang Postgraduate Research Grants Scheme (Grant No. PGRS2003180). N. A. Hashim also appreciates the Doctoral Research Scheme Award from Universiti Malaysia Pahang. The authors would also like to acknowledge the Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang, for providing the research facilities.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.focha.2023.100392.

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