

Encapsulation Performance of Maltodextrin-Gum Arabic Blends in Preserving Antioxidants and Physical Quality of Black Sapote (*Diospyros nigra*) Kombucha Analog

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HIGHLIGHTS

- ❖ Encapsulation of black sapote kombucha analog using maltodextrin and gum arabic mixture produced powder with several distinct physical qualities
- ❖ Bioactive compounds were able to be retained at a moderate level
- ❖ The 1:1 maltodextrin-to-gum arabic ratio produced powder with higher bioactivity than the other samples.

ABSTRACT

Black sapote kombucha (BSK) analog shelf life is limited by continuous fermentation, which can lead to deterioration. Spray drying can be used to convert the liquid into a more stable powder. Carrier agents such as maltodextrin (MD) and gum arabic (GA) can improve the physical properties of spray-dried products and protect bioactive compounds. However, the effect of different MD to GA ratios on the physical quality and antioxidant properties of spray-dried BSK analog has not yet been studied. Thus, identifying a suitable ratio is necessary to obtain a physically acceptable powder while retaining its antioxidant properties. This study aimed to study the impact of varying ratios of carrier agents on the physical and antioxidant properties of the spray-dried BSK analog. The study used three ratios of MD:GA(3:1; 1:1; 1:3). The 3:1 ratio had the lowest significant values of moisture ($2.90 \pm 0.15\%$), Carr index (35.17 ± 1.05), and Hausner ratio (1.55 ± 0.02). The yield ranged from 37.87% to 55.58%. The 1:1 ratio had the highest phenolic content and antioxidant activity (59.71% and 88.45%, respectively; $p < 0.05$). Overall, the 1:1 ratio performed well compared to the other treatments, but did not provide the highest protection for the bioactive compounds in the spray-dried BSK analog.



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INTRODUCTION

Black sapote, or well known as *Diospyros nigra*, is a fruit that originated presumably from Mexico (Carranza-Gonzalez, 2000, as cited by Jiménez González & Guererro-Beltrán, 2021), characterized by its dark brown-black pulp of the fruits when mature, which reaches $\leq 80\%$ of the total fruit, while the pericarp remains very thin (Arellano Gómez et al., 2005, as cited by Jiménez-González & Guerrero-Beltrán, 2021). The health benefits of black sapote mainly come from its high amount of dietary fiber, moderate amount of phenolic compounds, and high amount of flavonoid compounds (Moo-Huchin et al., 2014). Due to its highly climacteric nature, black sapote is a highly perishable fruit; besides its underutilization, posing a risk of increasing food waste. To preserve and incorporate its health benefits, black sapote can be used as a main substrate in the development of functional beverages such as kombucha, as recent innovation in kombucha development involves infusion with fruit juices, herbs, or natural extracts to create novel tastes, helping to reduce food waste and increase utilization of black sapote.

The kombucha itself is a slightly sweet/acidic fermented beverage made with an aqueous extract of tea leaves (fermented) utilizing a symbiotic culture of bacteria and yeast (SCOBY or pellicle), with a typical pH range of 2.3 to 3.8 (Kombucha Brewers International, 2023). Produced using sucrose-sweetened black or green tea, kombucha's main fermentation agents are acetic acid bacteria (AAB), yeast, and lactic acid bacteria (LAB). Some metabolites produced act as natural antimicrobial agents, which increase the shelf life (Dutta & Paul, 2019). Antioxidant activity in kombucha is mainly contributed by phenolics and polyphenol compounds that are present in the tea, such as catechins (Vohra et al., 2019), besides organic acids and metabolites that are produced by the fermentative microbiology ecosystem during fermentation, such as glucuronic acid (Martínez-Leal et al., 2020; Villarreal-Soto et al., 2018). When black sapote is used in place of tea, the product must be called kombucha analogs (Miranda et al., 2022).

Considering the fermentation process as a continuous process, over time, the organic acids will accumulate in the kombucha, posing health risks to the consumer (Nummer, 2013). The lowering of pH could also contribute to a decrease in the general sensory quality of the beverage to an unacceptable level (Chu & Chen, 2006). To stop the process, water activity and moisture content of the product must be lowered through spray drying process (Anandharamakrishnan & Ishwarya, 2015), while preservation of active compounds such as phenolics and flavonoids is achieved through the encapsulation process (Ray et al., 2016; Timilsena et al., 2020). However, materials like kombucha are not suitable to be spray-dried directly due to the presence of low molecular weight molecules, e.g., sucrose, fructose, and organic acids. This creates the problem of sticky powder attributed to the low glass transition temperature of the aforementioned compounds (Phisut, 2012). The spray drying process often uses carrier agents such as maltodextrin and gum arabic to encapsulate bioactive compounds and increase powder quality. Maltodextrin is a commonly used carrier agent and is reported to possess the ability to protect sensitive compounds from external environmental conditions such as high temperature (Ferrari et al., 2012). Furthermore, its high solubility, low viscosity, and low sugar content make it a preferred material to be used (Mahdavi et al., 2016). Gum arabic is also a regularly used carrier agent applied to the spray drying process due to its high solubility, optimum viscosity, and safety (Jafari et al., 2008). The combination of these two carrier agents has been used in a number of research and spray-drying parameters such as carrier agent ratio have a direct impact on the product's final properties.

Although maltodextrin and gum arabic have been extensively used in previous studies, the performance of the combined encapsulating agents is highly dependent on the compositional nature of the feed itself. The use of maltodextrin alone has been shown to produce powders with high stickiness in sugar-

and acid-rich foods (Lee et al., 2018). Moreover, it does not possess film-forming properties to improve the stability of the encapsulated material. It does, however, produce powder with higher yield (Saavedra-Leos et al., 2015). In contrast, gum arabic has better emulsifying and film-forming properties, in exchange for its lower yield (Mutavski et al., 2025). Previous studies have demonstrated that varying maltodextrin:gum arabic ratios significantly affect moisture content, encapsulation efficiency, antioxidant retention, glass transition behavior, and powder flow characteristics in fruit-based systems (Phisut, 2012; Ray et al., 2016). However, to date, no study has evaluated the use of maltodextrin:gum arabic in black sapote kombucha analog.

Various past research has also compared the effects of maltodextrin and gum arabic in different ratios. The combination often involves equal amounts of both encapsulating agents, higher maltodextrin, or higher gum arabic (Estupiñan-Amaya et al., 2023; Lee et al., 2025). Therefore, this study aims to assess the impact of using different ratios of MD (maltodextrin) and GA (gum arabic) as the encapsulation materials on the physical characteristics and antioxidant activity of encapsulated black sapote kombucha analog.

MATERIALS AND METHODS

Materials and reagents used

Black sapote fruits were purchased from *Embun Pagi* Farm, Sleman, Yogyakarta. Maltodextrin DE 12 and gum arabic were obtained from Baolingbao Biology Co. Ltd. (China) and Ingredion Sweetener and Starch Co. Ltd. (Thailand), respectively. Chemical reagents used include sodium carbonate (Merck), Folin-Ciocalteu reagent (Merck), methanol (Merck), DPPH reagent (Merck), and ascorbic acid (Himedia).

Preparation of black sapote kombucha

Unripe black sapote fruits were stored in a sealed container with 100 g of calcium carbide per 4 fruits to foster ripening. The use of calcium carbide in Indonesia as a ripening agent during this research period has not been regulated, and therefore is still commonly utilized. Once the fruits have reached maturity (dark skin, soft texture, and slightly sweet aroma), the soft mesocarp was separated from the skin and blended. The blended mesocarp was then filtered using cheesecloth before adding distilled water (1:1). The black sapote juice was subjected to heat treatment at 70°C for 1 minute. During heating, sugar was also added to reach 15°Brix. The juice was then cooled to room temperature, transferred to a sterilized jar, and SCOBY was added. The jar was then covered with cheesecloth. The fermentation process lasted for 7 days at room temperature (25-30°C).

Sample preparation for spray drying

The 7-day fermented black sapote kombucha analog was mixed with a combination of the encapsulating agent at 20% concentration (w/v). The target final total soluble solids (TSS) of the solution was 32%. The mixture was homogenized using a hand mixer (Bamix, Switzerland). Different encapsulation ratios of maltodextrin and gum arabic (1:3, 1:1, 3:1) were used as the distinguishing factor of the research. Samples were prepared in two biological replicates. All analyses were performed in three replicates.

Spray drying parameters

The spray drying process used a pilot-scale spray dryer LPG 5 Spray Dryer (SPM, Shanghai, China). The spray drying parameters were as follows: inlet air temperature (140°C), outlet air temperature (75°C), fan (45 Hz), feed flow rate (15 rpm), atomizer speed (250 Hz), air hammer action time (1s), and interval time (10s). The spray drying yield (expressed as a percentage) was calculated using the following equation: the weight of the final powder collected in the cyclone divided by the weight of total solids in the feed sample.

Moisture content and water activity

Moisture content was determined according to the AOAC Method 930.15 (AOAC International, 2023). 2 g of samples were dried in an oven using a crucible that had been heated in the oven previously to reach constant weight. The moisture content is then calculated as the weight difference between the initial and final constant weight after drying at 105°C. The water activity of the powder was analyzed using a PAWKIT water activity meter (Aqualab). As much as 2 g of powder was used.

Flowability and cohesiveness

Powder flowability and cohesiveness were measured using the Carr Index (CI) and Hausner Ratio (HR). Both require the measurement of tapped density (ρ_T) and bulk density (ρ_B). The procedure followed Camacho et al. (2022). Calculations were performed using the following **Equations 1 & 2**:

$$Carr\ Index = \frac{\rho_T - \rho_B}{\rho_T} \times 100$$

Equation 1. Carr Index equation

$$Hausner\ Ratio = \frac{\rho_T}{\rho_B}$$

Equation 2. Hausner Ratio equation

Solubility

The solubility of the powder was determined using a gravimetric method based on Kanpairo et al. (2012). 0.5 grams of sample (W_1) was placed into a 100 mL beaker and added to 5 mL of distilled water. The solution was filtered through a filtration paper (Whatman No. 4) (W_2), then dried at 105°C for 4 hours. The dried and cooled sample was then weighed (W_3). The percentage solubility can be calculated using the following **Equation 3**:

$$Solubility\ (\%) = 100 - \frac{(W_3 - W_2) \times 100}{W_1}$$

Equation 3. Percentage solubility equation

Color analysis

Colorimetric analysis was performed using a Spectral Colorimeter CS-410. Lightness (L), redness (a^*), and yellowness (b^*) values were determined. The Colorimetric analysis was performed on the BSK analog spray-dried powder.

Sedimentation test

Physical stability of the powder was assessed in solution. The procedure followed the method by Rivas et al. (2018). Briefly, 1 gram of sample was dissolved in 10 mL of distilled water. After 24 hours of storage, the sedimentation percentage was calculated as the difference between the initial volume and the sediment volume.

Reconstitution of encapsulated sample

For further analysis regarding the antioxidant activity, the powdered sample was reconstituted to the initial moisture content as in the initial feed according to methods by Agatha et al. (2021). After the moisture content of the powdered sample has been determined, the weight difference by evaporation is added back to the sample as water to return the powdered sample to its original moisture level.

Sample extraction

The powder sample was extracted following the methods by Lamuela-Raventos (2018). The sample was taken as much as 2.5 mL and was mixed with 80% methanol and incubated in a dark environment at room temperature for 30 minutes. The incubated sample was then centrifuged at 4000 rpm for 10 minutes, and the supernatant was collected.

Total Phenolic Content (TPC)

Assessment of the total phenolic content was determined using the Folin-Ciocalteu method following procedures based on Lamuela-Raventos (2018) with slight modifications. Briefly, 150 µl of sample was first mixed with 275 µl of 7.5% Na₂CO₃. After a 2-minute interval, 375 µl of 70% Folin-Ciocalteu reagent was added, and the sample was incubated in a dark environment for 30 minutes. An amount of 200 µl of the sample, along with the blank and control, was transferred to a 96-well microplate, and absorbance was measured at 765 nm. The calibration curve was also prepared using 0.01–2.5 µg/ml solutions of gallic acid. The result was expressed as milligrams of gallic acid equivalent per mL sample (mg GAE/ml sample).

DPPH radical scavenging activity

The antioxidant activity was measured using 1,1-diphenyl-1-picrylhydrazyl (DPPH) assay following Wern et al. (2016) with slight modifications. Ascorbic acid was used as a standard calibration curve (3.125–100 µg/mL, R²=0.999). 200 µL of the sample was combined with 2.8 mL of 0.1 mM DPPH and incubated for 30 minutes in the dark. The mixture was centrifuged for 5 minutes at 40000 rpm (25°C) to remove remaining residues and transferred into a 96-well plate. The absorbance was measured at 517 nm using a microplate reader. The DPPH radical scavenging activity was calculated using the following **Equation 4**, which is then used to calculate the antioxidant activity in milligram ascorbic acid equivalent per milliliter of sample (mg AAE/ml sample) shown in **Equation 5**.

$$\%RSA = \frac{Abs\ Control - Abs\ Sample}{Abs\ Control} \times 100$$

Equation 4. DPPH radical scavenging activity equation

$$mg\ AAE/mL\ sample = \frac{\%RSA - b}{a} \times DF$$

Equation 5. Antioxidant activity equation

Retention efficiency

After obtaining the results of the TPC and the antioxidant activity, the retention efficiency of the bioactive content was determined using the following **Equation 6** based on Iesa et al. (2023) and Xin et al. (2022). The efficiency was calculated as the ratio of the bioactive content of the powder compared to the bioactive content in the fresh kombucha.

$$Retention\ Efficiency\ (\%) = \frac{Bioactive\ container\ of\ powder}{Bioactive\ container\ of\ fresh\ kombucha} \times 100$$

Equation 6. Retention efficiency equation

Statistical analysis

Biological and technical replicate results were statistically analyzed using IBM SPSS Statistics (version 29). Results were expressed as mean values. Significant differences between samples were assessed using one-way ANOVA and Duncan Multiple Range Test as the post-hoc test at p<0.05.

RESULTS AND DISCUSSION

Physical characteristics

The physical properties of the encapsulated spray-dried black sapote kombucha with varying ratios of maltodextrin and gum arabic are shown in **Table 1**. The results show that the different ratios of encapsulating agents used significantly affected several physical parameters of the final powder, i.e., moisture content, water activity, Carr Index, Hausner ratio, and redness. Certain properties such as solubility, moisture content, and water activity exhibited results in a desirable range for a powder product, while others, including flowability, cohesiveness, and yield, demonstrated less favorable results.

Table 1. Physical properties of encapsulated spray-dried black sapote kombucha using different ratios of encapsulating agent

Properties	Maltodextrin : Gum Arabic Ratio		
	3:1	1:1	1:3
Solubility (%)	90.09±3.00 ^{ns}	90.18±2.52 ^{ns}	90.77±1.53 ^{ns}
Moisture (%)	2.90±0.15 ^a	3.70±0.34 ^b	5.19±0.43 ^c
Water Activity	0.28±0.02 ^a	0.25±0.01 ^b	0.24±0.01 ^b
Carr index	35.17±1.05 ^a	37.87±1.79 ^{ab}	41.47±4.04 ^b
Hausner ratio	1.55±0.02 ^a	1.62±0.05 ^{ab}	1.72±0.12 ^b
Yield (%)	49.65±5.93 ^{ns}	47.97±4.67 ^{ns}	41.60±3.73 ^{ns}
L	59.94±2.19 ^{ns}	58.96±1.18 ^{ns}	59.25±1.56 ^{ns}
a*	4.65±0.26 ^a	4.89±0.11 ^b	4.92±0.13 ^b
b*	17.95±2.46 ^{ns}	17.31±1.78 ^{ns}	17.48±1.36 ^{ns}
Sedimentation (%)	0	0	0

Note: Data were presented as mean ± standard deviation. Different letters between columns indicate significant differences at $p < 0.05$. No significant differences are denoted by “ns”.

The powder yield was not enough to be considered an effective spray drying system. The powder yield ranged from 38.96% to 53.84%, with an average yield of 46.4%. A number of studies noted that to consider a spray drying process to be successful, a minimum powder recovery of 50% is required (Chopda & Barrett, 2001; Zareifard et al., 2012). The low powder recovery rate could be attributed to the low concentration of encapsulating agents used and the characteristics of the black sapote kombucha analog. Multiple research on spray drying a fruit-based system use different encapsulating agent concentrations. A common method to determine the amount of encapsulating agent used is to measure the Total Soluble Solids of the final feed, which can range from 10% to 40% (Kim et al., 2021; Sharma et al., 2023). Higher concentrations were not used in this research due to possible difficulty in the atomization process with higher TSS. Another issue with spray drying fruit or vegetable juices is related to the presence of sugars and

organic acids (Shishir & Chen, 2017). These compounds have a low glass transition temperature (T_g), and when the drying temperature is increased to 20°C above their T_g , it will result in a sticky product due to its structure becoming rubbery and viscous (Bhandari et al., 1997; Fazaeli et al., 2012). Encapsulating agents such as maltodextrin and gum arabic can increase the T_g and reduce powder stickiness. Starch and its derivatives have high T_g and are complemented by the film-forming properties of gums (Miller & Gil, 2011). Therefore, an inadequate amount of encapsulating agent might contribute to product stickiness, which reduces the powder yield. Preliminary analysis of the black sapote juice shows the sample initially having a pH of around 5, then at the end of the fermentation process, the pH drops to approximately 3.4. This further suggests the production of acids by the microorganism in the kombucha analog. Another possible factor is the high viscosity of the feed solution. A study by Tonon et al. (2008) showed a reduced yield percentage when maltodextrin concentration was increased from 10% to 30%. A high-viscosity feed solution will result in droplets that will dry at slower rates, which in turn would cause the formation of wet powder within the chamber. A possible solution might be to increase the temperature of the solution to decrease the viscosity before initiating the spray drying process.

Moisture content is one of the critical properties for a powder product relating to its shelf life (Affandi et al., 2017). In the industry, a moisture content range of 1-6% is pursued to ensure the storage stability of powder products (Damodaran & Parkin, 2017). A lower moisture content will also minimize the possibilities of caking and agglomeration, which will affect powder flow and distribution (Tapia et al., 2020). Based on the results, all treatments produce satisfactory results below 6% moisture. The highest moisture content ($5.19 \pm 0.43\%$) was observed in the sample that contains the lowest proportion of MD, while the lowest value was recorded at $2.90 \pm 0.15\%$ from the highest proportion of MD. A similar observation was reported by Righetto and Netto (2005), who found that maltodextrin was more effective than gum arabic in reducing the moisture content of spray-dried acerola powder. Another study also noted that when gum arabic and maltodextrin are used as a wall material for encapsulation of eggplant peel extract, powder encapsulated using gum arabic presented a higher moisture content than maltodextrin (Sarabandi et al. 2019). This could be attributed to the chemical structural differences between the two carrier agents. Gums have a higher capacity to maintain moisture compared to a starch derivative such as maltodextrin (Nadeem et al., 2011). This difference could be explained by the highly branched structure a gum commonly possesses compared to starch derivatives, allowing it to have a higher water retention capacity (Sarabandi et al., 2018; Mohamed et al., 2025)

Water activity did differ significantly between the treatments, with values ranging from 0.23 to 0.3. Foods with water activity lower than 0.6 are deemed microbiologically stable; however, for powder-based products, in the industry the target is set to below 0.3 (Damodaran and Parkin, 2017). Samples that contained equal and higher ratios of gum arabic show a lower water activity value compared to samples encapsulated with higher maltodextrin. Similar behaviour was observed in previous studies as well, in which the results showed that maltodextrin exhibits a dried product with higher water activity when compared to other carrier agent materials, especially gum-based materials. Hay et al. (2025) noted that the addition of gum to maltodextrin improved the removal of water, thus reducing the water activity of the powder. This was also shown by the results of their study, in which the water activity of anthocyanin extracts microencapsulated using gum arabic, gidyaa gum, and maltodextrin was 0.26, 0.26, and 0.28, respectively.

Solubility is the final step of powder dissolution and is considered the key determinant of overall reconstitution quality (Fang et al., 2007). The solubility of the powder shows favorable results, with values ranging from 87.87% to 92.21%. Significant differences were not observed between the different treatments. A study by Mahdavi et al. (2016) investigated the effect of using a combination of maltodextrin,

gum arabic, and gelatin as an encapsulating agent for anthocyanin using spray drying. The results of the study also show a high degree of solubility ranging from 90 to 91% solubility of the powder. Both maltodextrin and gum arabic are considered to have excellent solubility in water.

Carr index and Hausner ratio were used to assess powder flowability and cohesiveness, respectively. Lower Carr index values indicate better flowability, while a higher Hausner ratio signifies greater cohesiveness, which is generally undesirable (Archaina et al., 2019). According to **Table 1**, all samples exhibited poor flowability and high cohesiveness. Carr index values range from 34.42 to 44.33, while Hausner ratio starts from 1.53 to 1.80. The poor flowability could be influenced by the moisture content of the sample as the sample with the highest proportion of gum arabic which exhibited the highest moisture also shows the highest mean flowability. The differences in the values were significant and similar trends were observed between the two parameters. Increase in the moisture content of powder has been observed to also increase cohesion between the particles of the powder, which in turn results in low flowability. Previous study by Santhalakshmy et al. (2015) also shows the flowability of spray dried jamun fruit juice powder to be in a similar range. Another possible reason is related to the aforementioned stickiness of the powder. Due to the samples containing sugars and organic acids, it may contribute to the cohesiveness of the powder particle and thus reduce its flowability.

According to the findings presented in **Table 1**, lightness value ranges from 58.12 to 61.49, the a^* value ranges from 4.46 to 5.01 indicating a tendency toward red—and the b^* value ranges from 16.05 to 19.69 indicating a tendency toward yellow. Only the redness values show a significant difference between the samples. In a study conducted by Oscar et al. (2023), the pulp color of black sapote was reported as 67.18 in L^* value, 4.6 in a^* value, and 29.6 in b^* value. The physical appearance of the powder can be seen in **Figure 1**.

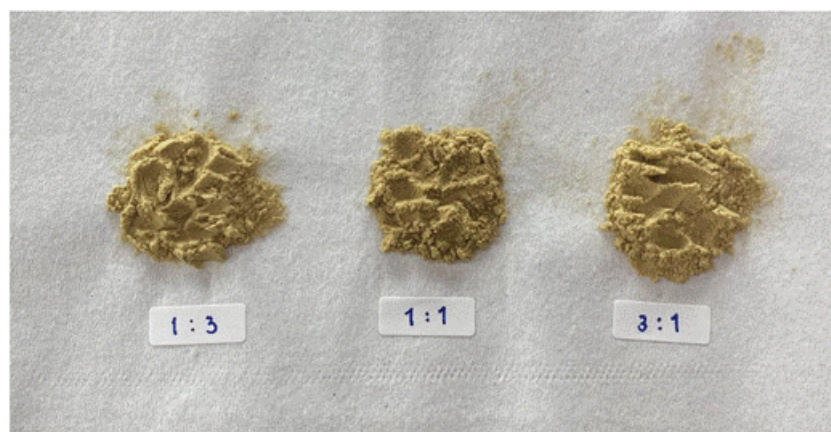


Figure 1. Physical appearance of the spray dried black sapote kombucha

High-temperature drying processes can induce Maillard browning reactions, which involve amino acid interactions leading to the formation of brown pigments and potential color degradation (Molaveisi et al., 2019). This suggests that the observed alterations in color attributes, such as changes in lightness and the a^* and b^* values could be influenced by Maillard browning reactions occurring during the drying process. The color of the carrier agent used in this study does not heavily influence the final product color due to both being generally white powder. Gum arabic powder itself is considered to be an off-white powder. However, the color changes may not present a visible change in the final color of the product. A study by Bednarska & Emilia (2020) also observed that different carrier type and concentration

combinations (maltodextrin and gum arabic) did not present statistically significant differences in the color of chokeberry juice powder.

High solubility of the particles suggests that nearly all of them dissolved in water, thus minimizing the presence of insoluble particles that could contribute to sedimentation. For powder products, low amounts to no sedimentation is preferred. All of the samples show 0% sedimentation. This absence of sedimentation persisted uniformly among all samples, regardless of varying maltodextrin and gum arabic ratios. Another alternative possibility explaining this result is the low sensitivity of the method., which could be further improved for future studies. After a prolonged observation of 24 hours, no sedimentation signs were evident. Such an absence suggests the substrate used in spray drying lacked insoluble particles. Notably, the substrate, kombucha, is aqueous-based and rich in water-soluble vitamins and essential minerals, facilitating effective dissolution (Martínez-Leal et al., 2018). Although our study elaborated on the sedimentation behaviors in spray-dried black sapote kombucha encapsulated with diverse maltodextrin and gum arabic ratios, further research should explore additional factors affecting sedimentation.

Antioxidant activity

Total phenolic content (TPC) of the spray dried powder with different ratios of MD and GA were obtained using the Folin-Ciocalteu method and expressed as mg GAE (gallic acid equivalent)/ml sample, while total antioxidant activity (TAA) were obtained using DPPH method and expressed as mg AAE (ascorbic acid equivalent)/ml sample. The retention efficiency (RE) was expressed as percentage of the retained TPC or TAA after the spray drying process. All data were summarized in **Table 2**.

Table 2. TPC, TAA, and their RE of each respective spray dried with different MD and GA formulations

Formula	TPC (mg GAE/ml sample)	TPC RE (%)	TAA (mg AAE/ml sample)	TAA RE (%)
3:1	1.27±0.44 ^{ns}	56.70±0.03 ^b	89.41±3.41 ^b	71.05±1.91 ^b
1:1	1.34±0.39 ^{ns}	60.25±2.20 ^c	111.31±7.04 ^c	88.50±4.00 ^c
1:3	1.15±0.30 ^{ns}	52.02±3.14 ^a	76.26±12.50 ^a	60.60±7.02 ^a

Note: Data were presented as mean ± standard deviation. Different letters between rows indicates significant differences at $p < 0.05$. No significant differences are denoted by “ns”.

Sample with MD: GA 1:1 ratio exhibited significantly higher ($p < 0.05$) TPC RE, TAA, and TAA RE compared to 3:1 and 1:3 ratio. This finding is consistent with previous studies by Safithri et al. (2020) and Nurhadi et al. (2024), which reported that MD:GA ratio of 1:1 was most effective in retaining bioactive compounds. Equal ratio between maltodextrin and gum arabic leads to a balanced properties of each carrier agent, leading to higher phenolic and antioxidant activity. Maltodextrin has good solubility and thermal stability, which support protection of bioactive compounds during drying (Xiao et. al., 2022). However, it has a low emulsifying ability. The addition of gum arabic compensates this limitation by enhancing film-forming properties and formation of stable emulsion prior to the spray drying process (Mutavski et. al., 2025). Furthermore, study from Lourenço et. al. (2020) demonstrated that using maltodextrin and gum arabic at a temperature of 150°C leads to the least significant changes in phenolic and antioxidant content even after 6 months of storage.

In terms of retention efficiency, all samples demonstrated medium encapsulation efficiency of 52.02-60.25% and 60.60-88.50% for phenolic compounds and antioxidant activity, respectively. Those

amounts are relatively low compared to the study by Lee et al. (2025), which was able to retain 89-91% with 4:1 maltodextrin and gum arabic ratio and an inlet temperature of 140°C. This suggests that wall material ratio and inlet temperature play a critical role in retaining phenolic and antioxidant activity. Another study by Rajabi et al. (2015), showed that bioactive compounds from saffron were able to be retained by at least 80% using a combination of maltodextrin, gum arabic, and gelatin mixture at 40% total solids. The current study uses a lower total solid percentages (32%) which could also influence the lower retention efficiency.

It was apparent that the spray-dried products retained lower TPC and TAA content compared to the liquid sample as reported by Guergoletto et al. (2020) and Mohsin et al. (2022) which also studies the effects of spray drying towards the antioxidant activity of powders. This may have occurred due to the utilization of heat during the spray drying process thus degrading the phenolic compounds that are heat-sensitive especially flavonoids, such as myricetin and quercetin that can be found in black sapote fruit, with the degradation temperature of 60°C and 120°C, respectively, which are much lower than the temperature used in this study (150°C) (Merino-Sanchez et al., 2022; Yao et al., 2014). Tatasciore et al. (2024) reported using spray drying to produce hop extract powder at higher temperature (150°C) produced samples with higher yield due to better heat efficiency. A high inlet temperature during spray drying is crucial to produce powder with acceptable moisture content. Lower inlet temperature may result in better retention of the bioactive compound, but the condition would be at the expense of physical stability. Other studies using similar encapsulating agents have used lower temperatures as low as 110°C or higher inlet temperatures of 170°C (Fazaeli et al., 2012; Arumugham et al., 2023). However, for this particular study, an intermediate temperature was chosen to balance the acceptable physical characteristics while still retaining some bioactive compounds. Other than heat, the atomization process also plays a role in the degradation of phenolic compounds, as exposure to oxygen leads to the oxidative degradation of phenolic compounds (Zhang et al., 2019).

CONCLUSION

This study has produced insightful results, particularly in providing more insights into the encapsulation of kombucha analogs using a combination of carrier agents. Different carrier agent ratios exhibited powders with several distinct physical properties. The equal ratio of maltodextrin and gum arabic seemed to provide acceptable results comparatively, with several physical parameters such as moisture content, water activity, and flowability being within an acceptable range. Furthermore, this ratio also resulted in the highest bioactivity comparatively, as assessed by the total phenolic content, antioxidant activity, and its retention efficiency. However, the overall retention efficiency remains moderate, and the process results in a moderate to low yield. The stability of bioactive compounds is a function of multiple combinations and interactions of factors such as carrier agent ratio and inlet temperature.

Future studies in relation to spray drying food materials rich in sugar and acid should take the result of this study into consideration. Improvements to the liquid feed formulation is needed in order to increase the yield of the process. Solutions such as increasing the total solids of the feed or the incorporation of other types of carrier agents could potentially improve the final product quality.

AUTHOR CONTRIBUTION

KFW: Conceptualization, Funding Acquisition, Supervision, Writing - Original Draft. **EVSM:** Conceptualization, Methodology, Writing - Review & Editing. **DPAPD:** Conceptualization, Methodology, Writing - Review & Editing. **LGR:** Formal Analysis, Investigation, Writing - Review & Editing. **NT:** Formal Analysis, Investigation, Writing - Review & Editing. **ACG:** Formal Analysis, Investigation, Writing - Review & Editing.

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COMPETING INTERESTS

The authors declare that they have no competing financial interests or personal relations that could affect and influence the quality of the work reported in this paper.

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ADDITIONAL INFORMATION

No additional information.

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