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Article

Triumfetta cordifolia mucilage and sweet potato dextrin as new hydrocolloid-based carrier with microencapsulation potential of polyphenols

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Abstract

Triumfetta cordifolia mucilage (MTC) is an alternative carrier for improvement of microencapsulation efficiency of bioactives by spray drying. *Ximenia americana* fruits are abundant in antioxidant bioactives (polyphenolic compounds). In general, fruits are subject to seasonal availability having a short lifespan. Microencapsulation is a preservation technique that guarantees the availability of fruits. Natural polysaccharides are strong potentials that can be valorized as encapsulating material. Therefore, this work has aimed to develop an encapsulating material from pyrodextrin of *Ipomoea batatas* and MTC for microencapsulation of polyphenols' *X. americana* juice. The addition of mucilage improved physicochemical parameters of *Ximenia* microcapsules. The blend leaded to higher encapsulation efficiency (>70%) than pyrodextrin alone (45%). The formulated carrier agent 1.5g mucilage/100g Dextrin hydrocolloids mixture had the first decision score of application properties. Mixtures of mucilage and pyrodextrin proved to be appropriate for encapsulating phenolic compounds, yielding powders that have promising potential for use in the functional food formulations.

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Microencapsulation; *triumfetta cordifolia*; pyrodexttrin; mucilage; polyphenols

Introduction

Microencapsulation process involves the use of polymeric wall materials to enclose bioactive compounds, such as polyphenolic compounds. These wall materials serve as a protective film, shielding the core materials from external factors like heat, light, and digestive enzymes (Yadav et al., 2019; Yao et al., 2020**)**. Currently, there are several encapsulation methods, including freeze drying, spray drying, and electrospray, that are easily accessible for enclosing bioactive molecules (Charles et al., 2022). The choice of encapsulating technique is determined by the ultimate objective of the microparticles (Ribeiro et al., 2020; Shishir & Chen 2017). Spray drying is a commonly employed technique in the food and pharmaceutical sectors for

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producing particles containing various bioactive substances (Zanoni et al., 2020). The technique described is characterized by its energy efficiency, ease of handling, speed, reproducibility, and scalability. Usually, the solution that is going to be sprayed is pushed to the nozzle and then sprayed into the hot air flow, which has a temperature range of 140-220°C. After evaporation, the powders are then directed down the bottom of the drying chamber at moderate outlet temperature range, usually between 50-80°C, in order to prevent any thermal deterioration (Sosnik & Seremeta 2015). The spray-dried powders are small, spherical particles with a mean particle size below 10 μm. They have low water activity, making them easy to handle and store (Carneiro et al., 2013; Favaro-Trindade et al., 2010). The use of natural polysaccharides in microencapsulation of bioactive components has become more popular in the food industry because they are biocompatible, non-toxic, and biodegradable (Charles et al., 2021; Yan et al., 2020). Natural polymers have the ability to enhance the attraction between molecules and water, as well as alter the qualities of their structure, such as rheology and physiochemical characteristics. Polysaccharides have diverse chemical structures, containing several reactive groups in their main chains and/or side chains, such as hydroxyl, carboxyl, and amino groups. Similarly, their physicochemical properties, such as water solubility and emulsification capabilities, may differ (Fathi et al., 2014). The choice of wall materials will have an impact on the qualities of the end products, including their shape, physical characteristics (such as solubility and swelling) as well as encapsulation efficiency of the active components.

Dextrins derived from starch exhibit excellent water solubility, low viscosity, a mild taste, and the ability to disperse (Coimbra et al., 2021**)** . Nevertheless, the emulsifying capability of dextrin is limited because of the hydroxyl groups it contains, which promote wettability and hence hinder its use in the encapsulation process (Waterhouse et al., 2017**)** . This characteristic can be altered by using additional coating ingredients, such as pectin, Acacia gum, and whey protein (Fernandes et al., 2014; Moser et al., 2017; Sansone et al., 2011). These modifications will enhance emulsification by decreasing the presence of hydroxyl groups or by creating complexes that enable the additional substance to function as an emulsifying agent (Faridi Esfanjani et al., 2017).

Triumfetta cordifolia is a shrub belonging to Malvacea family and is found in humid areas of tropical Africa. In cultivated land, *T. cordifolia* and other species of the same genus are common weeds that are difficult to eradicate (Fanwa et al., 2023). Extracts from leaves and stem bark are both edible. In the local region, the barks of the plant are used as thickening sauces, decanting agent, and flocculating agent in traditional beers. These barks' mucilages exhibit shear-thinning and gel-type viscoelastic behavior in aqueous extracts, which are non-thixotropic and have a yield point. Their thickening and gelling properties in aqueous solution are thus justified. *T. cordifolia* extracts added to corn or sorghum flour enhance the swelling of corn and sorghum fritters (Saïdou et al., 2021). The mucilage of *T. cordifolia* contains hydrophilic groups, including -OH and -COO- or -COOH, as well as acetylated hydrophobic moieties (Woguia et al., 2012). *T. cordifolia* mucilage is regarded amphiphilic due to the presence of both hydrophilic and hydrophobic groups. It was found that this mucilage has a molecular weight (Mw) of 4.07×10^6 Da. Fanwa et al. (2023) demonstrated its emulsifying characteristics.

Ximenia americana, a member of the Olacaceae family, is a small tree that can reach heights of 2 to 7 m. It can be found widely throughout tropical America and Asia, as well as in Africa, ranging from Senegal to West Cameroon. It is commonly known as hog plum or wild plum in English, inkoy and kol in Amharic and tchaboule in fufulde (Gemedo et al., 2005). The leaves of the plant are arranged alternately and have a lanceolate to elliptic shape. When the young leaves are crushed, they emit an aroma reminiscent of bitter almonds (Maundu et al., 1999). The fruits and leaves of *X. americana* have traditionally been used for medicinal purposes in both humans and animals (Le et al., 2011) . A study conducted examined various wild fruit trees, including *X. americana*. It was found that the fruits of this particular tree have high levels of antioxidant activity, attributed to their phenolic compound and flavonoid content. This suggests that *X. americana* could be a valuable source of antioxidants for medical purposes or as a dietary component to prevent cell oxidation in the human body (Almeida et al., 2016; Lamien-Meda et al., 2008). The desire for traditional nutritious fruits has risen, however, *X. americana* fruit, like other fruits, is highly perishable after being harvested, making it unappealing for consumption.

Modified starch and maltodextrin have been used as a substance that forms a protective barrier. It has been proven to be successful in the process of microencapsulating the beneficial elements of saffron through spray drying. In this process, maltodextrin is combined with Arabic gum and gelatin to create blends (Rajabi et al., 2015). Despite Arabic gum being deemed a viable material for walls, its relatively high cost poses a barrier on its usage. Consequently, there has been a push to find substitute polymers for arabic gum. Hydrocolloid combinations have been developed from the dextrin of sweet potato starch by using the mucilage of *T. cordifolia*. The hydrocolloid mixture's physiochemical characteristics, such as its flowability, wettability, and emulsifying capacity, improved as the percentage of *T. cordifolia* mucilage increased. The findings showed that the *T. cordifolia* mucilage can be a new source of polysaccharides, with the potential to generate a mixture of different polymers for application in the food industry, including as an encapsulating agent (Tsatsop et al., 2025).

The additional knowledge in the present work is the use of *T. cordifolia* mucilage having emulsifying properties to improve microencapsulation properties of dextrins from sweet potato starch. In fact, the blend of both materials as wall material in microencapsulation has not been investigated to the best of our knowledge. Thus, in the present research, a blend of two biopolymers to encapsulate phenolic compounds from *X. americana* fruit juice has been investigate. The effect of ratio of blending between mucilage and pyrodextrin on microencapsulation efficiency and physicochemical properties of spray dried powder of fruits extracts have been evaluated.

Method

Preparation of pyrodextrin from sweet potato (*Ipomoea batatas* Lam.) starch

The white sweet potato variety (*I. batatas* Lam.) root tubers were collected in the farm of Institute of Research for Agricultural Development (IRAD) at Ngaoundere. The plant has been authenticated and validated by Dr. Fawa Guidawa, a botanist and the head of the Department of Sciences and Technology of Organic Agriculture at Faculty of Science of the University of Ngaoundere. The extraction of starch was performed using the methodology described by Santos *et al.* (2016). The starch was evaluated, showing a moisture content of 6.15% (wet basis), solubility of 2.04%, and an amylose content of 30.02%.

The dextrinization of granule starch was carried out using the Tsatsop et al. (2024) approach. 250 g of sweet potato starch was weighed and 50 mL of hydrochloric acid (0.45 M) was sprayed on it, kept constant for 12 h at room temperature and under atmospheric pressure. Subsequently, the acidified starch was roasted in a (Memmert IN30, 32L, 230V, +5°C/300°C, 764.300030.00) oven with cavity dimensions (W×H×D) of 585 x 704 x 434 mm at 125 °C for 95 min. The product obtained was ground in a porcelain mortar, sieved (100 µm) packed in sealed plastic bags and placed in desiccator for further use.

Extraction of *Triumfetta cordifolia* stem bark polysaccharide mucilage

T. cordifolia stems were purchased from local market in Ngaoundere, Cameroon. The plant has been validated by Dr. Fawa Guidawa, a botanist and the head of the Department of Sciences and Technology of Organic Agriculture at Faculty of Science of the University of Ngaoundere. The methodology developed by Kaur et al. (2018) was used for mucilage extraction from fresh stem bark of *T. cordifolia*. The bark slices were mixed in distilled water at 50°C for one hour, using a bark/water ratio of 4 g/100 mL under agitation at 250 rpm. A 200-mesh muslin cloth was used to filter the mucilage extract from the stem bark. The filtrate was treated with a 1:2 v/v solution of 95% ethanol to precipitate polysaccharide mucilage. After 1h, the precipitates were centrifuged at 5000 rpm for 30 min and the solid precipitate was dried at 45°C for 12 h.

Preparation of encapsulating material (hydrocolloid mixtures): *T. cordifolia* mucilage blended with sweet potato pyrodextrin

A reconstituted solution of mucilage was prepared by introducing 1.5 g of mucilage (dry basis) concentration into a beaker containing 100 g of water. The mucilage was reconstituted in distilled water and heated to 50°C for 30 min while being stirred uniformly. The mixture was then kept in a refrigerator at 5°C for 12 h for the polysaccharide mucilage to fully hydrate. For the wall material preparation, the physical blending method has been used. Ji et al. (2012) approach with some modifications has been used. The percentages of mucilage were kept constant at 0, 0.5, 1.5 and 4.5 g of mucilage in 100 g of pyrodextrin respectively. For the preparation of the four different hydrocolloid mixtures, each proportion of the mucilage solution was weighed and a proportional mass of dextrin added into the extract in order to get the corresponding ratio, followed by mixing using an electric blender for 10 min in order to ensure a uniform mixture. The product was then dried at 45°C in an oven for 24 h. Afterward, the dry product obtained was ground, then sieved (100 µm). The various wall materials produced with moisture content ($kg_{water}/100kg_{\text{dry matter}}$) of 3.15%; 5.23%; 6.59% and 6.31% respectively for 0.0/100; 0.5/100; 1.5/100 and 4.5/100 (g *T. cordifolia* Mucilage/g dextrin) have been packed in sealed plastic bags and placed in desiccator until further spray drying microencapsulation application.

Preparation of extracts from fruits of *Ximenia americana*.

The yellow cultivar 'Tchaboule' (*X. americana*) used in this investigation was collected when fully ripe from the small savanna of Marza in Vina division, located at coordinates 7°14'59"N 13°34'59"E and an elevation of 1100 m above sea level, in March 2022. The plant has been authenticated and validated by the botanist Dr. Fawa Guidawa. The fruits were manually de-pulped and deseeded using stainless steel blades. The pulps were pulverized with a juice extractor (Moulinex Blender Mixeur; Faciclic Steel; Inox-LM320A10, 550 W). The fruit juice was obtained by passing it through a muslin filter. The resulting juice had a total solids content of 13 g/100 g (w/w), 10 °Brix, and a pH of 3.58. It was then stored at a temperature of -18°C until it was ready to be used for spray drying microencapsulation.

Microencapsulation process by spray drying of *X. americana* fruit extracts.

The spray drying experiments were carried out under the same operating conditions with the constant masses of wall material (encapsulating agent) used for all the wall material previously produced. These tests aimed to determine among the wall materials, which one would have a best encapsulation efficiency of the nutraceutical compounds of *X. americana* fruits extracts and which would also have better reconstitution properties. The spray drying conditions have defined based on literature and preliminary tests. Spray drying of fruits extracts was performed in a co-current small scale spray dryer (TFS-2LS SS304, Serial number 20210306), with two- fluid nozzle with orifice 0.7 mm in diameter, operating at: An inlet air temperature of 140°C; a feed inlet flow rate of sample of 400 mL/h or 20% of the max flow rate of Spray dryer model; An air supply flow rate of 73.5 m^3/h; A mass of aid dryer (wall material) of 40 g; 400 g *X. americana* fruits juice and the pressure of compressed air set at 6 bar. The powder recovery of the powder samples after spray drying was calculated using the following formula (Eq. 1), which relies on measurements of the dry matter:

$$\boldsymbol{Yield\ of\ spray\ drying}\ (\%) = \frac{\boldsymbol{Spray\ dried\ Powder\ obtained(g)}}{\boldsymbol{Total\ X.\ americana\ juice\ solid\ (g){+}wall\ material\ (g)}} \times \mathbf{100} \qquad (1)$$

Physicochemical characterization of formulated spray dried powder of fruits extracts.

Determination of Moisture content of *X. americana* fruit extracts powders. The moisture content of powder samples was determined gravimetrically by AOAC method (AOAC, 1995).

Determination of hygroscopicity of *X. americana* fruit extracts powders. Hygroscopicity was evaluated based on the method described by Moreira et al. (2009). Samples (1 g) were placed in a container at 25°C with a saturated NaCl solution (75.29% relative humidity). Samples were weighed after one week, and hygroscopicity was expressed as grams of adsorbed moisture per 100 g of dry matter.

Color measurement of spray dried microcapsule powders of fruit extracts. The To evaluate the effect of various materials on the physical appearance of spray dried fruit juice, the colorimeter (ColorMeter Max, CM2000156, 31mm Diameter and 102 mm height) was used to measure the hue angle of the powders. Consequently, the powders were enclosed in a transparent container. Subsequently, the colorimeter was positioned on top of it and the ColorMeter application was used to measure the values of a and b. The hue angle was calculated using the formula (Eq. 2):

$$H = Arctan(\frac{a}{b}) \qquad (2)$$

Where H = hue angle; a= measure of red for positive values and green for negative values; b= measure of yellow for positive values and blue for negative values. For H approaching 0° the hue approaches red; for H approaching 90° the hue approaches yellow; for H approaching

180° the hue approaches green and for H approaching 270° the hue approaches blue (Telis & Martinez-Navarrete, 2010).

Determination of solubility time of *X. americana* fruit extracts powders. Solubility time (s) corresponds to the time in seconds necessary to achieve complete dispersion of powder in water. An amount of distilled water (10 mL) at 25°C was poured into a 25-mL beaker. The powder sample (1 g) was placed around the beaker, and the time was recorded for the powder completely dispersed under agitation (Jinapong et al., 200**8).**

Determination of wettability time of *X. americana* fruit extracts powders. The wettability of the powder was measured according to the method reported by Jinapong et al. (2008). Wettability (s) corresponds to the Time in seconds necessary to achieve complete wetting of powder. An amount of distilled water (10 mL) at 25°C was poured into a 25-mL beaker. The powder sample (1 g) was placed around the beaker, and the time was recorded for the powder to become completely wetted.

Encapsulation efficiency of phenolic compounds of formulated spray dried powder of fruits extracts.

The microencapsulation efficiency was determined by measuring the amount of phenolics on the surface and the total amount of phenolics inside the microcapsules, using the method described by Robert et al. (2010).

Extraction of polyphenols present on the surface of *X. americana* fruit extracts powder. To extract phenolic compounds (P_S) from the surface, a solution of 10 mL methanol-ethanol combination (1:1) was applied to 0.2 g of juice powder. The mixture was allowed to undergo a period of inactivity for a duration of 30 min, as outlined by Robert et al. (2010).

Extraction of the total polyphenols (P_T) in *X. americana* fruit extracts powder. About 0.2 g of microcapsules were combined with a solution consisting of 10 mL of methanol, acetic acid, and water in a ratio of 50:8:42 (v/v/v). The mixture was vigorously agitated for 1 min and then passed through a filter. The resulting liquid was collected and thereafter stored.

The polyphenol content of the powder extracts was assessed using the methodology outlined by Robert et al. (2010), with a minor adjustment. 50 µL of extract was added to 1 mL of Folin-Ciocalteu reagent (diluted by a factor of 2) and 1 mL of sodium carbonate solution (with a concentration of 7.5%) was added. The absorbance was recorded at a wavelength of 765 nm after incubating for 30 min at room temperature using spectrophometer. The phenolic component concentration in the extracts was measured by comparing it to a calibration curve created using gallic acid as standard. The results were reported as mg of gallic acid equivalent per g of sample (mg EAG / g powder).

The encapsulation efficiency (EE) of total phenolic compounds in *X. americana* powder was determined by the following formula (Eq. 3):

$$EE = \frac{P_T - P_S}{P_T} \times 100 \qquad (3)$$

Where P_T is the total polyphenol contents (mg gallic acid per g of spray dried powder) and P_S is the surface polyphenol contents (mg gallic acid per g spray dried powder)

Statistical analysis

The data acquired during this study were analyzed using the analysis of variance (ANOVA) with the aid of STATGRAPHICS Centurion XVI program software. The statistical disparities between the average values were assessed using Duncan's multiple range test ($p < 0.05$).

Results or Findings

Spray dried powders yield

The influence of the mucilage/pyrodextrin ratio on the recovery of powder during the spray drying process of *X. americana* fruit extracts is presented in Table 1. An observed yield ranging from 49.55 to 64.99% is recorded.

Table 1. Physicochemical characteristics of *X. americana* juice microcapsules powders

		Encapsulating material (g mucilage/ 100 g pyrodextrin)			
Responses	**Units**	**0g/100g**	**0.5g/100g**	**1.5g/100g**	**4.5g/100g**
Yield of spray drying	%	51.89 ±2.13^{a}	57.45±1.18^{b}	64.99±3.32^{c}	49.55±2.15^{a}
Moisture content	g H_2O/100g powder (dry basis)	3.41±0.03^{c}	3.32±0.01^{b}	3.21±0.02^{a}	4.87±1.03^{d}
Hygroscopicity	g H_2O / 100 g dry mater	36.38±1.01^{a}	38.10±0.13^{b}	40.18±0.72^{c}	41.51±1.07^{d}
Wettability time	s	117±2.2^{a}	149±4.24^{b}	169±6.38^{c}	189±3.53^{d}
Solubility time	s	50±2.83^{a}	74±4.73^{b}	71±5.65^{b}	64±4.32^{b}

Values followed by the same letters within the section of a line are not significantly different ($p < 0.05$).

Moisture content and Hygroscopicity of spray dried *X. americana* fruits extracts microcapsules

The moisture content of formulated powder varied from 3.21 to 4.34 g/100 g (dry basis). The hygroscopicity value of the formulated powder obtained in the present study varied from 36.38 to 41.51 g/100 g, as shown in Tables 1.

Wettability and solubility time of spray dried *X. americana* fruits extracts microcapsules

The wetting times of the *X. americana* fruits extracts powders ranged from 117 to 189 s for the various wall materials (Table 1).

Encapsulation efficiency of polyphenols of *X. americana* fruit microcapsules

The Encapsulation efficiency of polyphenols in *X. americana* microcapsules were in the range of 45.45 to 80.23% (Table 2).

Color characteristic of spray dried *X. americana* fruits extracts microcapsules

The color of powders has a vital role in determining their appeal to consumers and serves as a visual representation of the original food product. While the food powder may have widespread applications in various products and offer significant health benefits, its lack of visual appeal may hinder its attraction to customers. The hue angle (the perceptual property of color) values of the *X. americana* fruit powders are presented in Table 2. These values obtained in this investigation ranged from 70.49 to 84.93, suggesting that the powder had a yellow color (Lee et al., 2013).

Table 2. Encapsulation Efficiency of the *X. americana* polyphenolic compounds microcapsules and color characteristic using hydrocolloid mixtures

		Encapsulating material (g mucilage/ 100 g pyrodexrin)			
Responses	**Units**	**0g/100g**	**0.5g/100g**	**1.5g/100g**	**4.5g/100g**
Surface	mg Eq GA/g powder	123.69 ±5.87^{d}	61.31±3.23^{c}	41.79±2.80^{b}	38.62±4.52^{a}
Total	mg Eq GA/g powder	205.69±1.26 ^{a}	198.12±4.15^{a}	200.20±2.15^{a}	204.97±3.42^{a}
Encapsulation efficiency	%	45.45±4.56^{a}	70.03±3.69^{b}	78.62±2.47^{c}	80.23±3.97^{c}
Hue angle	°	84.93±0.13^{d}	79.24±0.28^{c}	75.33±0.37^{b}	70.49±0.11^{a}

Values followed by the same letters within the section of a line are not significantly different ($p < 0.05$).

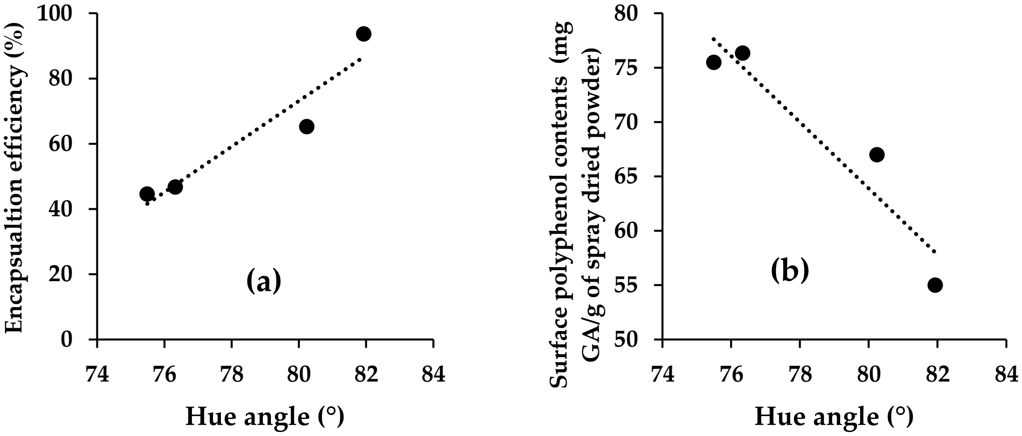

Figure 1. Diagram of correlation between Hue angle and Encapsulation efficiency (a) and Hue angle and surface polypnenols (b)

Multi criteria decision analysis

In order to decide on the proposition of the best encapsulating agent produced, a multi-criteria decision analysis has been done. Multi-Criteria Decision Making is one of the main decision-making problems which aims to determine the best alternative by considering more than one criterion in the selection process. It is one of the most accurate methods of decision-making, and it can be known as a revolution in this field (Aruldoss et al., 2013; Velasquez & Hester 2013). The analysis was carried out on all the *X. americana* juice powder produced (Table 3).

Thus, for each criterion as established in the specifications, a weight, measuring the importance of the criterion according to whether we would like to maximize it (division of the maximum value of the criterion by all the values of the different materials) or minimize it (division of all the values of the criterion by the min value of the criterion of the different materials), has been assigned. Then, the same coefficient was assigned to all these criteria so that the total sum of the coefficients was equal to 1.

Table 2. Decision matrix of the different wall material after spray drying of *X. americana* fruits extracts

Criterion	**Coefficient**	**Goal of Encapsulating material (g mucilage/ 100 g pyrodexrin)**			
		0g/100g	0.5g/100g	1.5g/100g	4.5g/100g
Yield of spray drying	0.143	0.798	0.884	1.000	0.762
Moisture content	0.143	0.941	0.967	1.000	0.659
Hygroscopicity	0.143	1.000	0.955	0.905	0.876
Wettability time	0.143	1.000	0.842	0.785	0.692
Solubility time	0.143	1.000	0.735	0.704	0.676
Encapsulation efficiency	0.143	0.559	0.870	0.977	1.000
Hue angle	0.143	0.830	0.890	0.936	1.000
Mark		0.876	0.877	0.901	0.809
Rank	-	3	2	1	4

This done, the decision matrix was established then, the score of each material was determined by the Excel software by adding the product of the weight of each criterion by its equivalent coefficient. Finally, the rank of each material was determined based on its grade.

Discussion

The mixture at 1.5g/100 g of mucilage and pyrodextrin exhibits higher spray drying efficiency in comparison to the other wall material. The addition of the *T. cordifolia* mucilage extract allows for the formation of a suitable matrix with pyrodextrin from sweet potato for encapsulating bioactive substances. The yield of the spray drying process is a significant factor that affects both the cost and efficiency of manufacturing. Bhandari *et al.* (1997) established that achieving a powder recovery rate of 50% is the benchmark for successful spray drying in laboratory-type spray driers. The results demonstrated that use a composite blend of various carriers leads to a greater output compared to using each carrier individually. This is due to the ability to maximize the practical benefits of each material by employing a combination of carrier agents. The results are in accordance to literature. In fact, Mirzaei et al. (2021) shown that the use of a combination of carriers of Arabic gum, whey protein concentrate, and maltodextrin in the formulation had a higher potential to encapsulate the anthocyanins of seedless black barberry compared to their use alone.

The moisture level of the powder produced by spray-drying is crucial as it indicates the length of time the powder may be stored without deteriorating. The water content of juice powder was minimally influenced by different carrier blends. The majority of formulations moisture content below 5%, which is the recommended maximum limit for water content in spray dried products (Fang et al., 2013). Water adsorption, evaluated as hygroscopicity, is a crucial element in powdered products due to its potential impact on the degradation of bioactive compounds such as phenolic compounds, as well as on powder qualities like its flowability.

The hygroscopicity of a product is determined by its composition, which includes low molecular weight sugar, organic acid, and moisture content. Additionally, the quantities of drying agents also have a role (Ferrari et al., 2011; Kuck & Noreña, 2016). From the result of the present study, it is observed that the increase in mucilage of *T. cordifolia* in the powder formulation tend to increase the hygroscopicity of the spray dried juice powder. This could be due to the hygroscopic behavior of the mucilage. The findings of this study align with the research conducted by Frascareli et al. (2012), which indicated that the hygroscopic properties of gum Arabic can be related to the greater levels of hygroscopicity exhibited by the powders. Nurhadi et al. (2012) found that the honey powder with gum Arabic exhibited a high level of hygroscopicity (>20%), in contrast to the honey powder with maltodextrin.

Wettability refers to the capacity of powder particles to overcome the surface tension between them and water. The wettability is significantly influenced by the surface content (such as lipids, proteins, and carbohydrates) and porosity of the particles (Fang et al., 2008). It is observed that the wettability time of spray dried juice powder increase with the concentration of mucilage in the formulation. This could be due to amphiphilic property of mucilage acting like emulsifying agent. According to a study by Wiliam & Philips (2000), Arabic gum has a higher degree of hydrophobicity compared to maltodextrin, which makes it more resistant to being wetted. Nurhadi et al. (2012) have had comparable outcomes with spray dried honey powder.

Table 1 provide the average solubility times for the spray dried powders of *X. americana* fruits extracts. The findings indicated that the concentration of mucilage in the encapsulating agent had a substantial impact on the average solubility times of the powders ($P < 0.05$). The solubility behavior of the spray dried powder exhibited a comparable pattern to the wettability behavior of the powders, as anticipated. The solubility times of the formulated juice powders were found to be positively correlated with the concentration of *T. cordifolia* mucilage in the formulation. The presence of hydrophobic structures in gums could explain this phenomenon (Koç & Dirim 2018). Junior et al. (2023) reported that the ratio of maltodextrin to gum arabic in the formulation of encapsulating agents was found to have a favorable impact on water solubility; microcapsules phenolic extract powders made with maltodextrin were more soluble, even if all of them had excellent solubility.

It is observed that the encapsulation efficiency of polyphenols of spray dried juice powder increase with the concentration of *T. cordifolia* mucilage in the formulation. The ability to retain phenolic compounds could be attributed to the combined effect of the pyrodextrin starch and *T. cordifolia* mucilage extract. Additionally, the *T. cordifolia* mucilage has emulsifying and film-forming properties that enable it to create a strong barrier around the phenolic compounds. The higher the concentration of *T. cordifolia* mucilage extract in the mixture, the more effective the encapsulation of the phenolic compounds. In fact, it has been stated that Arabic gum functions as a natural emulsifier and is a great film-forming substance due to its high branch hetero-polymer of sugars, glucuronic acid, and low protein connected to carbohydrate chains by covalent bonds. Then, Mirzaei et al. (2021) found mutual interaction between maltodextrin and Arabic gum in microencapsulation of anthocyanins of black seedless barberry (*Berberis vulgaris*). Saénz et al. (2009) found that the microencapsulation efficiency of phenols in cactus pear juice with maltodextrin ranged from 39.41% to 74.78%. Similarly, Robert et al. (2010) reported a microencapsulation efficiency of pomegranate active compounds using isolated soy protein blend to maltodextrin of 36.6 % to 82 %. According to the published results, viscosity of feed spray dried solution likely increases as the wall:core ratio rises, which reduces the movement of phenolic compounds to the surface. This effect may be linked to the way that the concentration of wall materials affects the formation of surface core forms around the drying droplets (Yazdi et al., 2021). Since *T. cordifolia* mucilage is commonly used as thickening agent (Fang et al., 2023), its addition in dextrin will tend to increase viscosity of suspension then increasing the encapsulation efficiency of phenolic compounds by film forming formation. The present work demonstrated for the first time that *T. cordifolia* mucilage could be useful for effectiveness of encapsulation of phenolic compounds due to its high branch hetero-polymer of sugars, uronic acids (glucuronic and galacturonic acids).

The kind and concentrations of the wall materials are factors that significantly affect the color characteristics of the microcapsules made by spray-drying, as earlier research have documented (Osorio et al., 2011; Shishir et al., 2014). Shishir et al., (2014) found that microcapsules made using DE10maltodextrins as the encapsulating material had a lower a^*/b^* value. Using DE 19–20 maltodextrin as the encapsulating agent, Osorio et al. (2011) showed an increase in color parameters ($+a^*$, $+b^*$) in the microcapsule production process. The present study found that as the concentration of *T. cordifolia* mucilage in the formulation increased, the Hue angle of the spray dried juice powder decreased. The intensity of the powder's yellow color diminished. This phenomenon can be attributed to the incorporation of bioactive components, particularly flavonoids, into the microcapsule. This incorporation occurs as the concentration of mucilage in the formulation increases. Consequently, a reduction in color is observed. An inverse correlation between Hue angle and encapsulation efficiency ($r = -0.947$; $P < 0.05$; df= 3) and positive correlation between the Hue angle and surface polyphenol ($r = 0.950$; $P < 0.05$; df= 3) are found in this study (Fig. 1). These correlations support the concept of encapsulation process aided by the presence of *T. cordifolia* mucilage in the formulation. According to Yousefi et al. (2011), the coloring ingredient in pomegranate juice may have been incorporated into the carrier agent and subsequently shielded from significant damage during the process of spray drying.

From Table 3, it can be seen that the wall material from blend 1.5g/100g (g mucilage/ 100 g pyrodexrin) would occupy the first place with a score of 0.901 followed by the 0.5g/100g blends with a score of 0.877, 0g/100g (3rd) with a score of 0.876 and finally the 4.5g/100g blend (4th) with a score of 0.809 for the materials produced. Based on this, it can be concluded that the 1.5g/100g g mucilage/ 100 g pyrodexrin) material is the suitable material for spray microencapsulation in this project.

Conclusion and Implications

This work involved the microencapsulation of *X. americana* fruit extracts using various carriers prepared by combining *T. cordifolia* mucilage and pyrodextrin derived from sweet potato starch using a spray dryer. The study found that increasing concentration of *T. cordifolia* mucilage in combination with pyrodextrin, enhances all physicochemical parameters of microcapsules, except for wettability time. The addition of *T. cordifolia* mucilage in the formulation significantly enhanced the encapsulation efficiency of phenolic compounds. Multi-Criteria Decision Making determined that a carrier agent blend with a ratio of 1.5g/100 g of mucilage to 100 g of pyrodexrin is the most suited material for spray encapsulation of *X. americana* fruit extracts.

The study demonstrated that the use of a blend of mucilage and pyrodextrin as carriers can effectively encapsulate bioactive compounds. From a strategic standpoint, it would be beneficial to conduct an optimization study with best materials in order to observe the impact of different spray drying process parameters on the effectiveness of encapsulation and the physicochemical attributes of the resulting microcapsule powder.

Additional research will be necessary to study the control release of phenolic compounds from the microcapsules for their use in functional food applications such as ingredient in functional foods formulations or nutraceutical formulations.

Declarations

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