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Effect of Different Carrier Agents on the Yield of Powered Plant Beverage Obtained by Spray Drying and Characterization of Physicochemical Properties

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ABSTRACT: Plant-based foods have become increasingly popular among consumers because of their health benefits and their sustainable nature. Powdered foods are a convenient option that are easy to store and transport. Therefore, this study aimed to develop a powdered plant-based beverage using a combination of chickpeas, quinoa, sweet potato, brown rice, and cocoa and evaluate the effect of different carrier agents (10% maltodextrin or 10% pea protein isolate) and dilution percentages (0, 30, 50, 70, and 90%) on the powder yield. The powered plant beverage was obtained by spray drying. M4 (maltodextrin4), with a 60% dilution and 10% maltodextrin, was selected for physicochemical characterization. X-ray diffraction analysis indicated that the resulting powdered beverage had an amorphous structure. The M4 sample exhibits a pH of 5.38 ± 0.09, titratable acidity of 0.78 ± 0.04, moisture content of 2.61 ± 0.22%, water activity of 0.23 ± 0.02, solubility of 52.29 ± 2.94, hygroscopicity of 5.00 ± 0.86, bulk density of 0.40 ± 0.0 g/mL, and rehydration time of 34.57 s. The content of ash was 0.51 ± 0.07%, protein was 3.85 ± 0.14%, lipid was 1.46 ± 0.18%, carbohydrates was 91.37 ± 0.15%, energy value was 119.91 ± 0.14 kcal/100 mL, and insoluble, soluble, and total fibers were 5.51 ± 1.24, 1.51 ± 0.42, and 6.69 ± 1.61%, respectively. The antioxidant activity was 99.36 ± 0.17%. NMR spectroscopy detected sucrose, maltotriose, and threonine as the primary organic compounds. In conclusion, this product shows promising market potential because of its favorable characteristics, such as its amorphous nature, nonhygroscopicity, satisfactory rehydration time, and antioxidant activity.

KEYWORDS: *vegetable powders, sustainable, plant-based food*

1. INTRODUCTION

Plant-based food products are produced exclusively with ingredients from plants, such as nuts, fruits, leaves, vegetables, grains, legumes, and roots.[1] Innovation in the food technology sector has contributed to these products having an appearance, aroma, flavor, and texture similar to those of products of animal origin, such as cheese, milk, and meat.[1] Moreover, plant-based foods have received much attention as a source of phenolic compounds, vitamins, minerals, and fiber, but mainly as a sustainable source of essential amino acids.[2]

The growing demand for plant-based food products is driven by people's increasing focus on health, environmental, and animal welfare concerns, as well as religious reasons, and the increase in the vegetarian population and those with allergies to animal proteins among consumers.[1] According to this trend, the global market for plant-based food is expected to reach US $113.1 billion by 2031.[3] In this scenario, the demand for powdered plant-based foods is also growing in the market because they are relatively easy to prepare for consumption, preservation, storage, and transport.[2] Consequently, the industrialization of plant-based food products is growing, and there is a need for knowledge about novel plant-based products.[4]

Powdered food products represent a large proportion of the total processed commercial foods on the market, occupying a range of applications such as dry beverages, instant coffee, powdered milk, sugar, and ice cream mixes.[2,5] These products can be defined as fine and cohesive solid particles obtained by partial removal of water through natural drying methods (e.g., sun drying or solar drying) or artificial drying (e.g., radiation, freeze-drying, osmotic drying, dielectric drying, or spray dryer).[2,5] Artificial dryers reduce drying time compared to natural drying methods. Moreover, some methods, like the spray dryer method, present benefits, such as a quick

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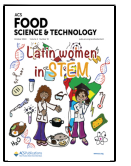

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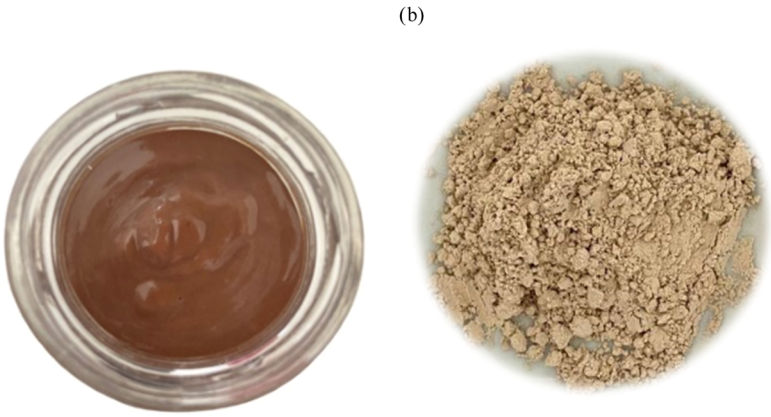

Figure 1. Appearance of plant-based cream (a) and powered plant beverage M4 (b).

procedure, continuous operation, and high yield. Thus, it is widely used to produce milk, fruit, and vegetable powders.[5,6]

However, despite the increase in demand for plant-based foods, the adoption of food innovations in this sector is still relatively limited, especially within the plant-based powdered food market.[7] Considering that the world population is expected to double by 2063, it is crucial to ensure the availability of sustainable food sources.[7] Vegetable proteins are considered a more sustainable and inexpensive source of protein than animal proteins.[7] The combination of varied plant protein sources such as rice (*Oryza sativa* L), quinoa (*Chenopodium quinoa*), and chickpeas (*Cicer arietinum* L) in a plant-based product emerges in an attempt to compensate for the lack of nonessential and essential amino acids since vegetable proteins are known to be nutritionally incomplete in relation to animal proteins. Thus, this study aimed to develop a new powdered plant beverage for spray drying and evaluate the powder yield using maltodextrin and pea protein as drying agents.

2. MATERIALS AND METHODS

2.1. Raw Material and Carrier Agents. Chickpeas (*C. arietinum* L) (Kicaldo Alimentos LTDA, SP, Brazil), quinoa (*C. quinoa*) (Excelência Selects Alimentos LTDA, CE, Brazil), sweet potatoes (*Ipomoea batatas*), brown rice (*O. sativa* L) (Camil Alimentos LTDA, SP, Brazil), sugar (Parceria Alimentos LTDA, CE, Brazil), maltodextrin (GastronomyLab LTDA, DF, Brazil), and cocoa (*Theobroma cacao*) (Mãe Terra Alimentos LTDA, SP, Brazil) were purchased from local markets in Fortaleza, Ceará State, Brazil. The carrier agents used were: maltodextrin (GastronomyLab LTDA, DF, Brazil) and pea protein isolate (NUTRATEC, Technology in Nutrients LTDA, SP, Brazil).

2.2. Plant-Based Cream Production. Chickpeas, quinoa, and brown rice were cooked according to the manufacturer's instructions, while sweet potatoes were cooked for 20 min. For the preparation of 100 mL of plant-based cream, the specified amounts of each ingredient (chickpeas 15.39 g, quinoa 15.39 g, sweet potatoes 7.69 g, brown rice 3.85 g, sacarose 5 g, maltodextrin 5 g, and cocoa 3 g) were weighed (analytical balance, Ohaus, Adventure) and processed in a blender (Philco, PLQ1400, Brazil) with 69.23 mL of potable water for approximately 20 min (Figure 1).

2.3. Spray Drying Conditions and Powder Yield. The type and concentration of carrier agents and the dilution percentage of the plant-based cocoa cream are presented in Table 1. The plant-based cocoa cream with the addition of carrier agents (10% maltodextrin or pea protein isolate relative to the weight of the cocoa cream) was dissolved in purified water to achieve a final dilution of 0, 30, 50, 60, and 70%. The samples were then subjected to spray drying (LM MSD 1.0 type, Labmaq, Brazil) at an inlet drying temperature of 160 °C, a compressed air flow rate of 30 L/min, a feed flow rate of 0.4 L/h, and a drying air flow rate of 3.0 m^3/min. The type and concentration of carrier agents were selected on the basis of previous studies that used similar carriers within a concentration range of 10% in the feed solution.[8,9]

Table 1. Dilution of Plant-Based Cream and the Type and Concentration of Carrier Agents before Spray Dryer[a]

	carrier agent (g)	plant-based cream (g)	purified water (g)	final dilution (%)
		Maltodextrin		
M1	20	180	0	0
M2	14	126	60	30
M3	10	90	100	50
M4	8	72	120	60
M5	6	54	140	70
M6	2	18	180	90
		Pea Protein		
PP4	8	72	120	60
PP5	6	54	140	70

[a]M: Maltodextrin; PP: Pea protein.

The powders obtained from the different formulations were weighed on an analytical balance and underwent yield analysis (Figure 1). All powders were prepared in duplicate, placed in plastic containers, blown out with nitrogen, sealed with Parafilm, and stored at −20 °C until further analysis. The powder yield was calculated as the ratio between the mass of solids present in the powder collected at the end of drying and the mass of solids present in the pulp destined for drying.

2.4. X-ray Diffraction. X-ray diffraction analysis of the powder was performed in a PANalytical X'Pert PRO diffractometer (model MDP) using cobalt radiation (kα1 λ = 1.7890100 Å) and operating at 40 kV and 40 mA. The optics consist of one mirror + two Ge220 monochromators and a 1/4° slit. The analysis was performed using a spinner at 2 rpm to improve the crystallite statistics, while a linear solid-state detector (Pixel) with 255 channels was installed on the diffracted axis (arm). Additionally, Bragg−Brentano geometry was employed. The range used was from "initial 2theta" to "final 2theta," with an angular step (2θ) of 0.013° and a step time of 68.85 s (velocity of 0.049°/s).[10]

2.5. Physical-Chemical Analysis. The plant-based cocoa cream and powder were subjected to acidity and pH using the methods adopted by the Association of Official Analytical Chemists.[11] pH was obtained by a pH meter (DLA-PH, DEL LAB).[11] The ash was determined by gravimetry after firing in a muffle furnace Q318A24 (Quimis, Diadema, SP, Brazil) (Procedure 018/IV), according to the Instituto Adolfo Lutz.[12] The determination of dietary fiber contents, including insoluble fractions (FDI) and soluble fractions (SDF), was conducted in accordance with the AOAC method 991.43 using the

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ANKON TDF dietary fiber analyzer (ANKON Technology Corporation, 2018).[13] Total dietary fiber (TDF) was calculated as the sum of the insoluble and soluble fractions following the recommended procedure of the same method. Lipid determination was carried out based on the American Oil Chemists' Society Am 5-04 method, utilizing the high-pressure and high-temperature extraction system in XT-15 Ankom equipment (ANKON Technology Corporation, 2009).[14] Protein determination was performed using the DUMAS method in Dumas NDA 701 Nitrogen/Protein Analyzer equipment (VELP, 2019), with EDTA employed as a standard, based on the AOAC 992.23 method.[15] The total carbohydrate content was calculated by the difference of proteins, lipids, ash, and moisture, eq 1. The ATWATER coefficient was used to determine the caloric value. Caloric values were calculated using the ATWATER coefficients (carbohydrates = 4; lipids = 9; proteins = 4). The total amount in grams of each nutrient determined in the analyses was multiplied by their respective coefficients.[16]

$$\%\ \text{carbohydrates} = 100 - (\%\ \text{protein} + \%\ \text{lipids} + \%\ \text{ash} + \%\ \text{moisture}) \quad (1)$$

2.6. Water Activity, Hygroscopicity, and Bulk Density (ρb). Water activity (A_w) was determined at 25 °C using Aqualab 4TE equipment (Meter Group, Inc., Pullman WA, United States). Hygroscopicity measurements were performed according to the method proposed by Cai and Corke.[17] A mass of 1 g of each powder was placed in a desiccator containing saturated NaCl solution (relative humidity of 75.3%) at 25 °C. The gain in weight due to moisture adsorption was recorded daily for 1 week, and hygroscopicity was expressed as g of adsorbed moisture/100 g of sample.

To determine ρb, 2 g of powder was transferred to a 50 mL graduated cylinder and the occupied volume was noted. Bulk density was calculated by dividing the mass of the powder by the volume occupied in the cylinder and was expressed as g/L.[18]

2.7. Solubility and Rehydration. The solubility was determined following the method of Eastman and Moore,[19] modified by Cano-Chauca, Stringent, Ramos, and Cal-Vidal.[20] Powder samples and distilled water (1 g:100 mL) were homogenized under magnetic stirring at 2000 g^{-1} for 5 min and centrifuged at 3000 g^{-1} for 5 min. Finally, an aliquot of the supernatant (25 mL) was transferred to a Petri dish and immediately placed in an oven at 105 °C for 5 h. After being cooled in a desiccator, the Petri dish was weighed, and the difference in weight determined the mass of the sample contained in the dish. Powder solubility was expressed as a percentage and was calculated using eq 2.

$$\text{solubility}\ (\%) = \frac{\text{dried supernatant}\ (\text{g})}{\text{initial amount of powder}\ (\text{g})} \times 100 \quad (2)$$

Rehydration of the powder was performed by adding 2 g of the material to 50 mL of distilled water at 26 °C. The mixture was agitated in a 100 mL low-form glass beaker with a Heidolph magnetic stirrer (No. 50382, MR 82, Heidolph Instruments GmbH & Co. KG, Schwabach, Germany) at 800 g^{-1} using a stirring bar with a size of 2 mm × 7 mm.[20]

2.8. Color. Color was determined by CIE-LAB coordinates using a Hunter Labscan colorimeter (Hunter Associates Laboratory, Inc., Reston, VA) with the aid of Easy match QC 4.1 software, which determines the following values: a^* (green/red), b^* (blue/yellow), c^* (saturation), h^* (color angle), and L^* (luminosity), as recommended by the Commission Internationale de l'Eclairage.[21]

2.9. NMR Spectroscopy Analysis. The NMR experiments were developed to investigate the organic composition of the plant-based cocoa cream and powder. 59.2 mg was directly mixed with 600 μL of deuterated water (99.9% purity) and centrifuged for 2 min, and the supernatant was transferred to 5 mm NMR tubes. The NMR experiments were performed on a Bruker DRX 500 (11.7 T; 499.6 MHz) spectrometer equipped with a 5 mm inverse detection probe and an actively shielded z-gradient. The data were acquired in triplicate under quantitative condition: 5 min waiting before starting the NMR analysis to stabilize the sample temperature with the probe fixed at 298 K; calibrated hard pulse to 90° (9.75 μs); acquisition time of 5.0 s; and relaxation delay of 20.0 s determined by the inversion–recovery pulse sequence (7 times the longest T_1 of the observed protons, to achieve 99.9% of complete spins relaxation accuracy).[22] In addition, the ^{1}H NMR spectra were acquired with 16 scans using the "noesypr1d" pulse sequence (Bruker library) for nondeuterated water suppression at δ 4.79, and 64 k of time domain points in a spectral window of 20.0 ppm. The ^{1}H NMR spectra were processed by applying exponential multiplication of the FID by a factor of 0.3 Hz, and Fourier transformation of 16 k points. Phase correction was manually performed, and the baseline correction was applied over the entire spectral range. The identification of the constituents in the samples was performed through a two-dimensional (2D) NMR experiment, as ^{1}H–^{1}H *g*COSY, ^{1}H–^{13}C *g*HSQC, and ^{1}H–^{13}C *g*HMBC. The results were compared to the existing data in open-access databases (www.hmdb.ca) and literature reports.[23−25] The COSY experiments were obtained with a spectral width of 18,028.1 Hz in both dimensions; 4 k × 256 data matrix; 16 scans per t1 increment, and a relaxation delay of 1.0 s. The HSQC experiments were acquired with an evolution delay of 1.7 ms for an average ^1J(C,H) of 145 Hz; 4 k × 256 data matrix; 32 scans per t1 increment; spectral widths of 18,028.1 Hz in f2 and 36,057.7 Hz in f1 and relaxation delay of 1.0 s. The HMBC experiments were recorded with an evolution delay of 50.0 ms for ^{LR}J(C,H) of 10 Hz; 4 k × 256 data matrix; 64 scans per t1 increment; spectral width 18,028.8 Hz in f2 and 14,529.3 Hz in f1, and relaxation delay of 1.0 s.

The compounds with no overlapped resonances were quantified using the Eretic2 method (TopSpin 3.1). A standard solution of sucrose (5.0 mg/L) was used to calibrate the equipment/software, and the probe file was updated with all of the parameters required for the determination of the concentrations in unknown samples. The combined uncertainties of the methods were estimated from the analytical errors (balance and micropipet), sucrose purity (99.9%), and spectral acquisition (triplicate).

2.10. Antioxidant Activity. A 0.3 mL aliquot of the sample in an aqueous solution at a concentration of 200 μg per milliliter is combined with 3 mL of a reagent comprising four millimolar ammonium molybdate, 28 mM sodium phosphate, and 0.6 molar sulfuric acids. The resulting mixture is tightly sealed in tubes and incubated in a water bath at 95 °C for 90 min. Post-cooling, the absorbance is determined at 695 nm using a UV spectrophotometer, with a solution containing 0.3 mL of water and 3 mL of the reagent serving as the blank. Ascorbic acid is employed as a reference substance at a concentration of 200 μg per milliliter. The antioxidant activity (%) is subsequently computed using eq 3, accounting for the fact that ascorbic acid exhibits 100% antioxidant activity (Prieto, Pineda, & Aguilar, 1999).[26]

$$\%\ \text{antioxidant activity} = \left(\frac{\text{sample absorbance} - \text{blank absorbance}}{\text{ascorbic acid absorbance} - \text{blank absorbance}}\right) \times 100 \quad (3)$$

2.11. Statistical Analysis. Results are expressed as the mean ± standard deviation and were calculated using Prism version 9.3.1 for Windows (GraphPad Software, CA). Data were analyzed by the student under 95% confidence level. All analyses were performed in triplicate.

3. RESULTS AND DISCUSSION

3.1. Powder Yield. The impact of varying adjuvant and dilution percentage conditions on the powder yield is depicted in Figure 2. The results show that the powder yield ranged from 14.49 to 40.01%, with the highest yield achieved at a 60% dilution with 10% maltodextrin. Maltodextrin is a commonly used carrier agent known for its neutral flavor, cost-effectiveness, and high solubility in water. Numerous studies

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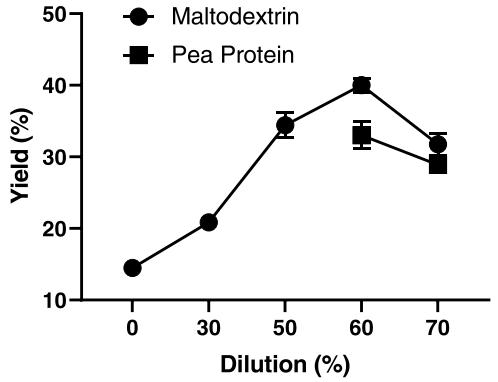

Figure 2. Effect of maltodextrin (M) or pea protein (PP) and dilution percentage on powder yield.

have demonstrated that maltodextrin can reduce the apparent viscosity of droplets, thereby facilitating the atomization and drying of liquids.[27] Additionally, it enhances the hygroscopicity, glass transition temperature (T_g), microencapsulation efficiency, and antioxidant activity of the final product, while also yielding powders with reduced stickiness.[27] This carrier was chosen for the study due to these attributes and the favorable yields observed with maltodextrin addition. Given the higher yield percentage, sample M4, with a 60% dilution and 10% maltodextrin, was selected for physicochemical characterization.

Unfortunately, the utilization of pea protein to facilitate the freeze-drying process of the plant-based cocoa cream proved to be unfeasible. Despite efforts to introduce pea protein at concentrations of 0, 30, and 50%, the resulting samples exhibited increased viscosity, leading to equipment blockage and precluding the formation of the powdered product. The elevated viscosity may be attributed to the intricate nature of pea protein's structure.[28]

3.2. X-ray Diffraction. The X-ray diffractogram of the powdered plant-based beverage is shown in Figure 3. Only a broad peak was observed at approximately 25° 2θ, thus indicating an amorphous powder. This result is satisfactory because an amorphous structure powder dissolves more rapidly

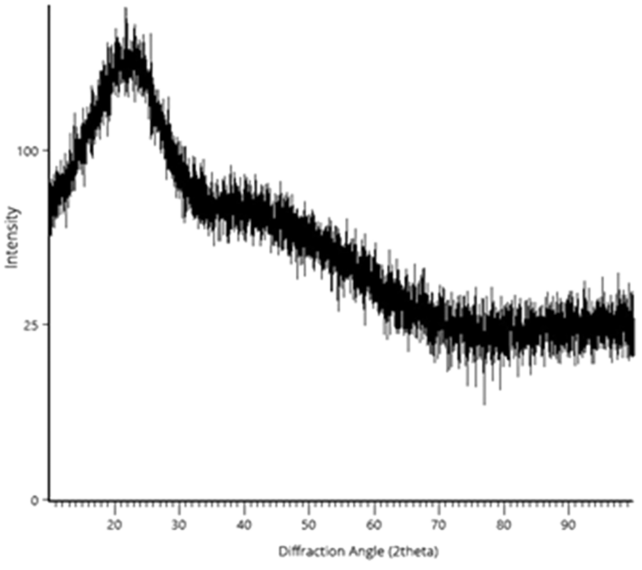

Figure 3. X-ray diffraction patterns of the M4 powder.

than a crystalline one; therefore, its application in the beverage industry is more efficient.[29] A similar result was found by Dankar et al.,[30] who investigated the crystallinity of potato powder and identified only a broad peak centered at approximately 16°.

It is important to highlight that the characteristics of the raw material comprising the product and the type of treatment it undergoes can influence its crystallinity. According to Fu et al.,[31] products containing starch (such as the powder investigated in this study) may exhibit compromised crystallinity levels when subjected to different processes. For example, atomization drying can change the ordered structure of starch granules, rendering them amorphous.[32]

3.3. Physical-Chemical Properties. The physical-chemical characterization of the plant-based cocoa cream and M4 powdered plant beverage is demonstrated in Table 2. The

Table 2. Physicochemical Characterization and Color Parameters of Plant-Based Cream and Powdered Plant Beverage M4[a]

properties	plant-based cream	powered plant beverage—M4
acidity (%)	0.15 ± 0.02^b	0.79 ± 0.03^a
pH	5.12 ± 0.06^b	5.38 ± 0.09^a
moisture (%)	89.39 ± 0.24^a	2.81 ± 0.09^b
ash (%)	0.18 ± 0.01^b	0.51 ± 0.07^a
soluble fiber (%)		1.52 ± 0.42
insoluble fiber (%)		5.51 ± 1.24
total fiber (%)		6.69 ± 1.61
lipid (%)		1.46 ± 0.18
protein (%)		3.85 ± 0.14
carbohydrate (%)		91.37 ± 0.15
kcal/100 mL		119.91 ± 0.14
A_w	0.99 ± 0.00^a	0.24 ± 0.02^b
hygroscopicity (%)		5.00 ± 0.86
bulk density		0.40 ± 0.00
solubility (%)		52.29 ± 2.94
rehydration (s)		34.57 ± 0.59
color L^*	28.73 ± 0.07^b	73.26 ± 1.24^a
a^*	10.69 ± 0.08^a	4.99 ± 0.21^b
b^*	17.84 ± 0.16^a	14.21 ± 0.22^b
C^*	20.80 ± 0.13^a	15.06 ± 0.27^b
H	59.08 ± 0.09^b	70.62 ± 0.49^a

[a]Values are presented as mean ± standard deviation. Values in the same row with at least one equal letter do not differ at the 5% level of significance.

results obtained between the samples showed significant differences, indicating that the drying process led to changes in the product's composition. pH is used to measure the acidity or alkalinity of foods and represents an important parameter for food stability. The high acidity and pH values in the M4 powdered plant beverage indicate a lower susceptibility to contamination by undesirable microorganisms.[33]

The moisture content and A_w values for plant-based cocoa cream were significantly reduced in the M4 powdered plant beverage, highlighting the efficacy of drying in producing products with extended shelf life since higher moisture content and A_w contents indicate increased perishability. Similar results have been demonstrated by Samborska et al.[34] for moisture content (1.3−5.2%) and A_w (0.079−0.259) in the different plant beverages. It is important to note that lowering the A_w to below 0.6 confers satisfactory microbiological stability to the

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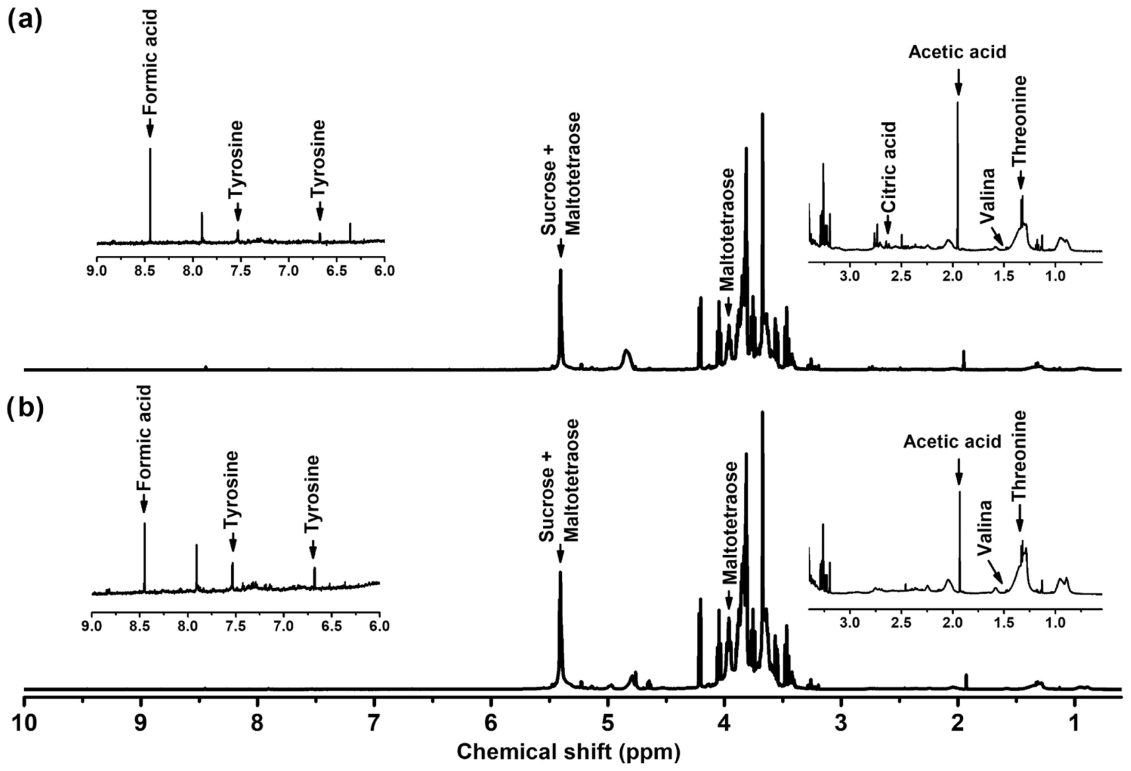

Figure 4. ^{1}H RMN spectra of the plant-based cream (a) and powder (b).

product.[35] The ash content of the plant-based powder was higher than that of the plant-based cocoa cream, indicating an increase in the inorganic matter concentration following the drying process. The low ash value obtained in this study is associated with the high moisture content of the plant-based cocoa dessert.

The high level of carbohydrates found in this study (91.37 ± 0.15%) in the M4 powdered plant beverage is attributed to the natural presence of carbohydrates in the brown rice, quinoa, sweet potatoes, and chickpeas used in the dessert.[36,37] The protein content (3.85 ± 0.14%) is mainly sourced from quinoa and chickpeas. Quinoa, a time-honored crop, is highly valued for its exceptional protein content and wide range of bioactive compounds known for their valuable medicinal properties.[37] The low lipid content (1.46 ± 0.18%) in the M4 plant-based powder reflects the low lipid amounts in the raw materials. The low lipid values and high fiber content (6.69 ± 1.61%) can help manage calorie intake, control body weight, and reduce the risk of diabetes, obesity, and cardiovascular disease.[36−38]

3.5. Hygroscopicity and Bulk Density. The hygroscopic nature of powdery food products depends on their particulate dimensions and chemical composition.[39] The maltodextrin selected for this study serves as a carrier agent, intended to effectively minimize hygroscopicity, reduce dusting, and prevent reactions with incompatible ingredients. Powdered products with less than 10% hygroscopicity percentage are considered nonhygroscopic.[39] Considering that the result obtained for the M4 powdered plant beverage was equal to 5% in the hygroscopicity test, the powdered product can be considered nonhygroscopic (Table 2).

Higher hygroscopicity values, ranging from 11.67 to 16.68%, have been reported in sweet potato powders by Arebo, Feyisa, Tafa, and Satheesh.[40] Low hygroscopicity values are preferable because powders with high hygroscopicity can absorb water from the environment and consequently have a sticky characteristic.[41]

Bulk density is a measure of the mass of several particles in a granule or powder divided by the total volume they occupy.[42] In this study, the bulk density is shown in Table 2. The bulk density value was higher than that found in rice powder (0.577 ± 0.005 g/mL) and lower than that obtained in chickpea powder (0.46 ± 0.003 g/mL).[42] The temperature used in spray drying may have influenced the attainment of the powder, which is considered to have a low bulk density. Higher temperatures provide faster evaporation rates and products with lower moisture content and more porous or fragmented structural characteristics.[43] Furthermore, using maltodextrin as a carrier agent could also have contributed to the value obtained for bulk density, as it could reduce the moisture content and adhesion of thermoplastic particles.[43,44]

3.6. Solubility and Rehydration. Basic measuring methods can be used for quality control as long as a comprehensive understanding of a powder's behavior is obtained.[45] The ideal powder should be easily wet, sink into the liquid, and dissolve without forming lumps. Achieving this ideal behavior can be challenging due to the small size and structure of the particles produced during manufacturing. The solubility of a powder is a critical factor that significantly impacts industrial processes involving the incorporation of the powder into an aqueous phase.[45] Thus, solubility analysis is a fundamental step in the characterization of powder products. Powders used as ingredients in the food industry that exhibit a higher solubility value favor their reconstitution in water or other liquids.[45] In the present study, the solubility of the M4 powdered plant beverage was found to be 52.29%, which was higher than the values obtained by Arebo et al.[40] in spray-dried sweet potato powders, ranging from 15.36 to 30.15%. The differences in solubility values could be due to the type of

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carrier substances used in the drying method, the specific characteristics of the powders, such as moisture content, and the size and physical condition of the particles.[20,46] Reduced rehydration time is an important and desirable quality attribute for powered food products.[47] Inadequate dissolution or dispersion of dehydrated food powders can significantly disrupt food processing, leading to unfavorable outcomes for the final product quality and consumer satisfaction.[47] In this study, the average rehydration time of the M4 powdered plant beverage was 34.57 s (Table 2). This is lower than that reported by Goula and Adamopoulos.[43] who investigated the characteristics of orange juice concentrate powder and found rehydration times ranging from 77 to 200 s.

3.7. Color. According to the results (Table 2), the plant-based cream exhibited reduced luminosity compared with the powder sample, suggesting a significant change in light reflection after the drying procedure. Positive values for a^* parameter, indicating the presence of red tones, were observed in the samples, higher in the plant-based cream (10.69 ± 0.08) than in the powder (4.99 ± 0.21). Likewise, the samples presented positive values for the b^* parameter, suggesting the presence of yellow tones in the plant-based cream (17.84 ± 0.16) stronger than in the powder (14.21 ± 0.22). The combination of positive results from coordinates a^* and b^* is the result of a brown color that is typical of cocoa-based foods and their derivatives.[48]

Regarding chromaticity, the wet sample showed greater color saturation, with a higher chroma than that of the powder sample, corroborating the visually perceived intensity of the color. The shade angle (H), in turn, indicated that the plant-based cream presented a tendency for a color between red and yellow (59.08 ± 0.09), whereas the powder presented a more yellow color (70.62 ± 0.49).

3.8. NMR. NMR spectroscopy was used to identify and quantify organic compounds in the creamy plant-based cocoa dessert. Figure 4 presents the ^{1}H NMR spectrum (δ 0.8−6.0) of the samples solubilized in deuterated water (D_2O), with amplified regions related to some short-chain organic acids and amino acids and sugars. The identified components' data were compared to the existing data in open-access databases (www.hmdb.ca) and literature reports.[49] As illustrated in Figure 4, sucrose dominated the main organic composition of the creamy and powder samples, followed by maltotriose and threonine. However, some organic compounds, such as valine, tyrosine, acetic, and citric acids, were also detected at minor concentrations. Sucrose, a disaccharide composed of glucose and fructose, provides a sweet and flavorful taste to vegetables.[50] Similarly, maltotriose, a trisaccharide comprising three glucose molecules linked with α-1,4-glycosidic bonds found in maltodextrin, also contributes to the sweetness and flavor profile of vegetables.[51] Both of these substances occur naturally in fruits, vegetables, and nuts. Furthermore, threonine, an essential amino acid, plays a crucial role in maintaining a proper protein balance within the body. This amino acid supports various bodily functions, including the formation of healthy bones, collagen, elastin, and teeth.[52] Additionally, threonine contributes to the function of the immune system.[52] Table 3 describes the quantitative results, corroborating the higher concentration of sucrose.

3.9. Antioxidant Activity. The powder exhibited an antioxidant activity of 99.36 ± 0.17%, which can be attributed to the high concentration of phenolic compounds in the raw material. The use of maltodextrin as a carrier and the drying parameters employed likely contributed to the preservation of the antioxidant compounds. Previous studies focusing on the antioxidant capacity of spray-dried powders, particularly with maltodextrin addition, have shown its effectiveness in preserving phenolic compounds and flavonoids, thereby maintaining high antioxidant activity in various powders such as those derived from peanut skins, flaxseed, and bergamot juice.[53−55] Encapsulation with maltodextrin during the drying process is believed to protect antioxidant compounds, resulting in enhanced antioxidant activity retention and bioactive compounds' stability.[56,57] The impact of the spray dryer's inlet temperature on the powders' antioxidant activity has also been widely investigated. Studies have indicated that temperatures around 150−160 °C, consistent with the parameters utilized in this study (i.e., 160 °C), yield favorable outcomes for preserving antioxidant compounds, especially when combined with maltodextrin.[53−58]

Table 3. Organic Compounds Identified in the Plant-Based Cream and Powder

	organic compounds (mg/mL)	
	plant-based cream	powered plant beverage—M4
valine	0.00531 ± 0.00010	0.01636 ± 0.00055
threonine	0.08505 ± 0.00499	0.22676 ± 0.01150
acetic acid	0.02630 ± 0.00040	0.04336 ± 0.00064
citric acid	0.07541 ± 0.00447	
sucrose	3.79287 ± 0.16579	1.01673 ± 0.29394
maltoriose	2.62 ± 0.05196	9.11 ± 0.07211
tyrosine	0.00354 ± 0.00664	0.02716 ± 0.00040
formic acid	0.00664 ± 0.00005	0.01120 ± 0.00019

The study of M4 powdered plant beverage using maltodextrin or pea protein and varying water dilution percentages during spray drying yielded promising results. The powder yield increased with higher dilution until reaching 60%, with the highest yield observed using maltodextrin as the carrier agent. X-ray diffraction analysis revealed an amorphous structure that is ideal for food applications. The powder's acidity, pH, moisture, and water activity levels indicate decreased susceptibility to contamination, ensuring product stability. Additionally, the powder displays nonhygroscopic behavior, good solubility, rapid rehydration, and antioxidant activity, making it well suited for practical applications. The use of maltodextrin and the drying temperature may have contributed to the observed low bulk density. However, the color analysis indicated changes post-drying, the powdered plant-based beverage retained typical cocoa-based food tones. These characteristics position the product as a promising option for exploration and commercialization in the food industry. Further research could involve sensory tests with consumers and comprehensive chemical composition analyses.

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ABBREVIATIONS

rpsrevolutions per second
Awwater activity
ρbbulk density
NaClSodium chloride
D_2ODeuterated water

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