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STUDY OF THE EFFECTS OF THE MICROENCAPSULATING AGENT ON SPRAY DRIED GOAT'S MILK

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Abstract: Spray drying enhances food biochemical stability by converting liquid formulations into powders. This method relies on carrier agents — additives introduced beforehand as solid mass fractions — which affect the final sensorial, physicochemical and morphological properties of the resulting powders. The overall purpose of this study was to evaluate the quantitative impact of different carrier agent configurations on several physicochemical attributes of spray dried goat's milk. Drying was performed in a pilot-scale spray dryer at 150 ºC, using immediately before thawed goat's milk supplemented with three configurations of carrier agents: (1) maltodextrin; (2) maltodextrin combined with arabic gum; (3) modified starch. pH, ºBrix and total solids were analyzed on the fresh goat's milk, while the powders were characterized for particle size, moisture, ash content, water activity, solubility, reconstituted pH and ºBrix, as well as storage stability, colorimetry, and thermogravimetric behavior. The formulations resulted in goat's milk powder with mean particle sizes ranging from 19.54 to 23.13 µm. Modified starch as a carrier agent was associated with a lower activity (0.127), while moisture content ranged from 2.08 % to 4.54%, ash content from 1.64 % to 2.63 %, and solubility in water between 85.24 % and 94.09 %. Upon reconstitution, soluble solids varied from 10.0 to 11.2 ºBrix, and the samples exhibited slightly more acid, with pH ranging from 5.83 to 6.27. Water activity and moisture were within acceptable preservation standards. Dehydrated goat's milk showed moderate luminosity with a predominantly yellow hue. All three formulations displayed thermogravimetric analyses curves with independent decomposition profiles.

Keywords: Carrier agent; Food drying; Goat milk powder.

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ESTUDO DOS EFEITOS DO AGENTE MICROENCAPSULANTE NO LEITE DE CABRA DESIDRATADO POR ASPERSÃO

Resumo: A secagem por aspersão melhora a estabilidade bioquímica dos alimentos, convertendo formulações líquidas em pós. Este método utiliza agentes carreadores — aditivos introduzidos previamente como frações de massa sólida — que afetam as propriedades sensoriais, físico-químicas e morfológicas finais dos pós resultantes. O objetivo geral deste estudo foi avaliar o impacto quantitativo de diferentes configurações de agentes carreadores em diversos atributos físico-químicos do leite de cabra seco por aspersão. A secagem foi realizada em um secador por aspersão em escala piloto a 150 °C, utilizando leite de cabra imediatamente antes do descongelamento, suplementado com três configurações de agentes carreadores: (1) maltodextrina; (2) maltodextrina combinada com goma arábica; (3) amido modificado. O pH, o teor de sólidos totais (ºBrix) e o teor de sólidos totais foram analisados no leite de cabra fresco, enquanto os pós foram caracterizados quanto ao tamanho de partícula, umidade, teor de cinzas, atividade de água, solubilidade, pH e ºBrix após reconstituição, bem como estabilidade de armazenamento, colorimetria e comportamento termogravimétrico. As formulações resultaram em leite de cabra em pó com tamanhos médios de partículas variando de 19,54 a 23,13 µm. O amido modificado como agente carreador foi associado a uma atividade menor (0,127), enquanto o teor de umidade variou de 2,08% a 4,54%, o teor de cinzas de 1,64% a 2,63% e a solubilidade em água entre 85,24% e 94,09%. Após a reconstituição, os sólidos solúveis variaram de 10,0 a 11,2 ºBrix e as amostras apresentaram acidez ligeiramente maior, com pH variando de 5,83 a 6,27. A atividade da água e a umidade estavam dentro dos padrões aceitáveis de conservação. O leite de cabra desidratado apresentou luminosidade moderada com uma tonalidade predominantemente amarela. Todas as três formulações apresentaram curvas de análise termogravimétrica com perfis de decomposição independentes.

Palavras-chave: Agente carreador; Desidratação de alimentos; Leite de cabra em pó.

1 INTRODUCTION

In Brazil, goat farming is largely concentrated in the Northeast and Southeast regions, with the state of Paraíba leading the country in production. Owing to the physiological climatic resistance of *Capra hircus*, the Cariri mesoregion of Paraiba, goat's milk and other products from local, small-scale goat farming in the northeastern semi-arid region provide income, employment, and food for farmers and communities in the region (Costa *et al*., 2007). The Brazilian semi-arid has historically been chosen for the economic exploitation of goats: 5.6 million liters of goat's milk produced in Brazil comes from animals collectively owned by producers in the state of Paraíba (Lima Júnior *et al*., 2024). Easily digestible fats and proteins (Kurniawati; Suryani, 2023), potassium, magnesium, and phosphorus, as well as vitamin A (the deficiency of which is linked to the development of certain types of eye diseases and tumors), are healthy contents that are lost through microbial overgrowth (Lu; Wang, 2017).

As a consequence of food drying technology - broadly exploited in the dairy sector - an extension of several orders of magnitude in the lifespan of the original, fresh milk has been noted. Spray drying is an effective method of this technology proposed by literature and industry (Baeghbali; Niakousari; Farahnaky, 2016). Spray drying serves a fundamental purpose in the food industry, as it enables the production of easily handled and durable powders from liquid products. The process involves atomizing liquid material into fine droplets that are rapidly dried by warm air. This technology offers advantages, including swift processing, preservation of nutrients that are particularly thermosensitive, and improvement of ingredient functionalities. In spite of certain challenges — particularly those related to the high energetic requirements, stickiness issues in formulations containing sugars or high protein content, and the potential loss of heat-sensitive nutrients — spray drying remains an essential tool in the food industry (Shubhashish; Kumar; Rajput, 2025).

Furthermore, spray drying is a cost effective, widely used, encapsulation technique for the production of functional foods. Studies on the optimization of atomization conditions for producing functional goat's milk powder enriched with pomegranate peel extract have measured parameters such as the concentration of the added carrier agents at the levels of 5, 10 and 15 %, and inlet drying temperatures of 160, 183 and 200 ºC. The optimal conditions were determined to be a concentration of 12.10 % and inlet temperature of 178.98 ºC. Some of the physicochemical attributes for the optimized functional goat's milk powder included a moisture content of 3.85%, a solubility index of 95.55%, hygroscopicity of 1.91% and average particle size of 6.23 µm (Nisa; Ansori; Mubarok, 2025).

Powdered milk has a broad spectrum of predictive physical, biochemical, and functional attributes relevant to the future commercial performance of the batch and the analysis of its production parameters, which are established in organizations mainly through empirical evaluations (Boiarkina *et al*., 2018). The acceptability of powdered milk products depends largely on their nutritional aspects and the speed of reconstitution of their direct applications, including baby formula and soluble milk (Reddy *et al*., 2014). However, powdered milk's main attribute is its long shelf life.

To meet consumer demands for the use of ingredients of non-synthetic origin, food processing companies have emphasized the use of components such as maltodextrins — polysaccharides derived from the acidic or enzymatic hydrolysis of corn starch, biochemically composed of D-glucose with alpha-1,4 bonds — of varied DE (dextrose equivalent) classification, and the polymeric extract of *Acacia Senegal*, known as gum arabic (Honarao, 2023). Gum arabic, consisting mainly of D-glucuronic acid, L-Rhamnose, D-Galactose, and L-arabinose, is highly soluble in water, and is known to impart emulsifying and thickening properties (Dagliya; Satyam; Garg, 2022). Studies have shown that modified starch, whose molecules are equipped with incorporated lipophilic or hydrophilic regions, as a carrier agent, increases products' biochemical stability and retention capacity through spray drying. The sensorial, psychochemical, nutritional properties and the product yield are, therefore, partly established by the selection of the encapsulating agent (Pui; Saleena, 2022).

The overall intent of this investigation was to examine the quantitative impact generated by distinct configurations of microencapsulation agents on several psychochemical attributes of spray dried goat's milk.

2 METHODOLOGY

2.1 Materials

The goat's milk sample was obtained by milking a healthy population of goats from Sítio Barriguda, located in the municipality of Barra de Santa Rosa, Paraíba, Brazil. The herd was regularly fed on open-air pasture, the diet being supplemented with cottonseed and spineless cactus. The fresh sample of goat's milk to be pulverized was not subjected to any thermal treatment and was frozen without the supplementation of any food preservatives or other additives. The microencapsulation agents used were tasteless maltodextrin 20DE and gum arabic, both supplied by Pryme Foods (Sorocaba, Brazil). Capsul modified starch, an encapsulator of fats extracted from corn, was supplied by GastronomyLab (Brasília, Brazil).

2.2 Statistical analysis

The statistical significance of the independent parameters measured in triplicate was established by analysis of variance (ANOVA) using the Tukey test for the evaluations of water activity and water and ash contents, liquid reconstitution properties, and for a colorimetric analysis. The confidence interval used to determine the statistical relevance of the performance of each microencapsulation agent was 95% ($p \leq 0.05$).

2.3 Sample preparation

The analytical samples were prepared by mixing the preestablished composition quota of microencapsulation agents in fresh goat's milk, being the frame of reference the total solids measurements, as shown in Table 1:

Table 1 – Ratio of carrier agents added to goat's milk

Solution	Maltodextrin	Gum arabic	Mod. starch
1	11%	Zero	Zero
2	6%	5%	Zero
3	Zero	Zero	11%

The three solutions were homogenized independently using a Fisatom model 713D mechanical table stirrer. Given the solutions of fresh goat milk and microencapsulation agents, the acidity and the refractometric index of the homogeneous mixtures were measured in triplicate, together with the fresh milk.

2.4 Spray drying

The drying step was developed in the pilot scale spray dryer model SD 5.0, manufactured by Labmaq do Brasil (Ribeirão Preto, Brazil), to dry approximately 3000 g of goat's milk, immediately before defrosted and mixed with the established amount of carrier agents. The operating conditions were as follows: air temperature of 150 ºC; operating pressure of 4 bar; feed flow equal to 2 $L.h^{-1}$; blower flow equal to 2 $m^3. min^{-1}$; compressed air flow from the sprayer equal to 30 $L.min^{-1}$. The output temperature was measured at 94.0 ºC.

2.5 Psychochemical analysis

Acidity was measured using a digital pH meter for solutions manufactured by Testo (Titisee-Neustadt, Germany), model 206-pH1, according to the (Adolfo Lutz Institute, 2008). Quantification of the dry soluble material contained in the milk sample was accomplished by the bench refractometer model WYA-2S, manufactured by Nova Instruments (Piracicaba, Brazil), applying the electronic correction under the operating temperature measured at 26.8 ºC.

Solids analysis was performed in the laboratory digital balance model ATY224, manufactured by Shimadzu (Kyoto, Japan). The samples, measured in dehumidified beakers, were subjected to constant heating at 105ºC for 24 hours (Adolfo Lutz Institute modified, 2008) in the laboratory oven (model Luca-80/150 of Lucadema, São José do Rio Preto, Brazil). The total solids content was then obtained by Equation 1, where variables equal the masses of the dried content and of the colloidal sample:

$$\%Totalsolids = \frac{m_{dry}}{m_{suspension}} x100\% \quad (1)$$

The granulometry was performed on a representative sample of solid dried goat's milk in the electronic particle size analyzer manufactured by CILAS (Orleáns, France), model 1090. The particle size study was derived from the analysis of diffraction at the incision of the particles by two laser beam sources, including a mechanical stirring step.

The measurement of water activity under a fixed temperature of 30 ºC was executed in the electronic analyzer Labmaster-aw, manufactured by Novasina AG (Lachen, Switzerland).

Following the steps described by the Adolfo Lutz Institute (2008), a triplicate of dehumidified porcelain crucibles each containing 1 g of material, was heated at 105 ºC for a period of 24 h in the Lucadema oven, model Luca-80/150, to gauge the water content of spray-dried goat's milk.

The ash content was measured by adapting the method of Araújo *et al*. (2006). Dehumidified porcelain crucibles containing 1 g of fresh goat's milk were sent to the laboratory muffle furnace at 550 ºC for 24 h.

The water solubility index of goat's milk powder was established, with adaptations, following the method described by (Cone; Ashworth, 1947). Two grams of dried powder were stirred in 200 g of distilled water in the magnetic agitator Q21-2, manufactured by Quimis (Diadema, Brazil). Representative aliquots of 50 mL were centrifuged at 2600 rpm for 5 minutes at 30 ºC on the tabletop centrifuge NT815, manufactured by Novatecnica (Piracicaba, Brazil). A supernatant sample of 12 mL was heated in the laboratory oven for 24 h. The solid solubility index was calculated by Equation 2:

$$\%Watersolubilityindex = \frac{m_f * V_{solvent}}{m * V_{aliquot}} * 100\% \quad (2)$$

The evaluation of reconstitution capacity of spray dried powder was quantified by the method described by (Almeida; Silva; Ferreira, 2021). A sample of 2 g of dried goat's milk was stirred in a volume of water determined by Equation 3:

$$V_{water} = \frac{m * (1 - TS)}{TS} \quad (3)$$

The general psychochemical conservation of the three samples was measured by re-evaluating the water composition and water activity after 30 days of storage in a commercial storage freezer at -15 ºC, as described by Nunes (2019).

Colorimetric analysis was fulfilled by the method described by (Afshari-Jouybari; Farahnaky, 2011). The factors L*, a*, and b* were achieved employing the proprietary software *Adobe® Photoshop® 2019* and photographs of samples of spray-dried goat's milk under conditions free from light interference, over an opaque, white surface, taken with the camera of model A99, from Sony (Tokyo, Japan). The lens used was 28-70mm F2.8, 5.6 aperture, external flash with light control by the TTL method. The distance between the lens and the samples was kept constant. Colorimetric factors, detected at different points of the photographs, were calibrated by the linear regression adjustment by Equations 4 through 6:

$$L_i = A * L_{pi} + B; \text{A = 1,168 e B = -1,167} \quad (4)$$

$$a_i = A * a_{pi} + B; \text{A = 1,152 e B = -3,225} \quad (5)$$

$$b_i = A * b_{pi} + B; \text{A = 1,012 e B = 4,041} \quad (6)$$

And, in addition, by the second order polynomial regression model by Equations 7 through 9:

$$L_i = A * L_{pi}^2 + B * L_{pi} + C; \text{A = 0,002, B = 0,991 e C = 1,7219} \quad (7)$$

$$a_i = A * a_{pi}^2 + B * a_{pi} + C; \text{A = 0,007, B = 1,386 e C = -1,441} \quad (8)$$

$$b_i = A * b_{pi}^2 + B * b_{pi} + C; \text{A = 0,003, B = 1,049 e C = 2,592} \quad (9)$$

Thermogravimetric characterization is a form of analysis that determines the physical performance of materials under thermal decomposition conditions (Verruck *et al.*, 2018). In this study, samples of spray-dried goat's milk were decomposed in the detector model DTG-60H, manufactured by Shimadzu (Kyoto, Japan), in an argon atmosphere, at a flow rate of 50 $mL.min^{-1}$ and a rate of temperature change rate of positive 5 $^{\circ}C.min^{-1}$, up to 600 °C.

3 RESULTS

3.1 pH, ºBx and total solids of fresh goat's milk

Three samples of 20 mL each of fresh goat's milk were subjected to triplicate analysis of pH and refractometric index, electronically adjusted in a standard temperature of 23.1 ºC.

The results gave a mean of 6.49 ± 0.00577 for pH, vaguely acidic, and 11.2 ± 0.416 ºBx. The extent of the acidity was similar to the average of 6.69 obtained by Chornobai *et al*. (1999). Razali *et al*. (2021) recorded a measurement of ºBx in the range of 10.2 in a sample of goat's milk that had not undergone any thermal or chemical processing.

The total solids analysis consisted of the treatment of 10 g samples of fresh goat's milk, and was ascertained to reside within the range of 12.91 ± 0.0473 % as shown in Table 2:

Table 2 – Percentage of total solids in fresh goat's milk

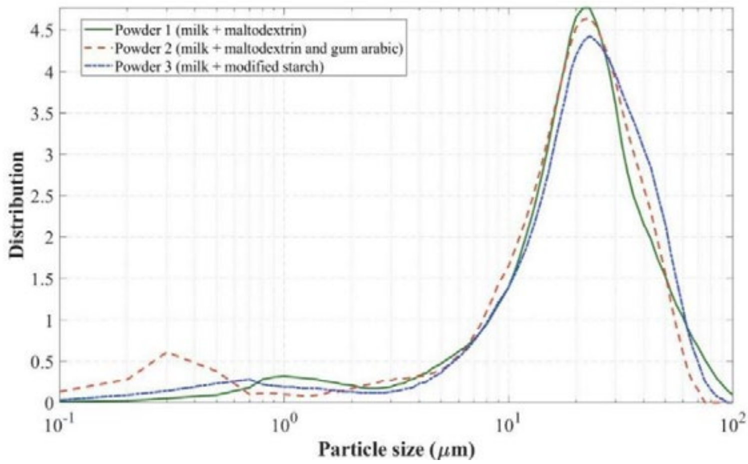
Run	%TS
1	12.86 %
2	12.95 %
3	12.93 %

The study by Albanell *et al*. (2003), using spectroscopic analysis of goat's milk, found an average solids content of 14.06% in a population of 131 samples. As reported by the United States Department of Agriculture, a 100 g portion of goat's milk contains 87.03 g of water.

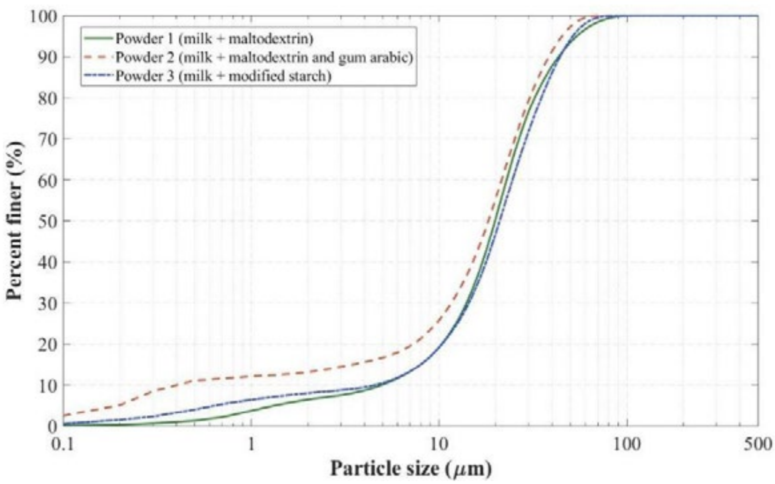
3.2 Particle size

The graphs (a) and (b) of Figure 1, pertinent to the histograms and the behavior of the bimodal distribution and the cumulative granulometry curve of each of the configurations, indicated that the configuration obtained from the mixture of maltodextrin and gum arabic obtained a finer morphology than the other two, and respectively for the pulverized ones related to the maltodextrin, maltodextrin-gum arabic and modified starch configurations, average particle diameters of 22.61 μm, 19.54 μm and 23.13 μm, respectively.

Figure 1 – Curves of electronic granulometry analysis of powders (1), (2) and (3)



(a) Distribution



(b) Accumulative

The diameter measurements obtained at 10%, 50%, and 90% accumulation for each of the powders are shown in Table 3:

Table 3 – Mean particle size and particle sizes of spray-dried powders at values of 10%, 50%, and 90% accumulation

Carrier agent	10%	50%	90%	Mean particle size
Maltodextrin	4.96 μm	19.86 μm	43.25 μm	22.61 μm
Maltodextrin, gum arabic	0.40 μm	18.31 μm	38.45 μm	19.54 μm
Mod. starch	4.57 μm	21.02 μm	44.05 μm	23.13 μm

Hammes (2013) gauged in the process of atomizing buffalo milk alongside soy lecithin as the carrier agent at 1% on a dry basis, a specific mean diameter of approximately 10.97 μm. Nisa; Ansori; Mubarok (2025) found, for spray dried functional goat's milk powder an average particle size of 6.23 µm.

3.3 Water activity

The water activity was determined to reside between 0.127 and 0.189 (at the standard temperature of 30ºC). A study with an analogous methodology, for soy lecithin added to goat's milk, was done by Fonseca *et al*. (2011) to determine a range between 0.12 and 0.14. The results obtained are presented in Table 4:

Table 4 – Water activity of spray-dried powdered goat's milk

Carrier agent	a_w
Maltodextrin	0.137 ± 0.0100^{ab}
Maltodextrin, gum arabic	0.189 ± 0.0376^{a}
Mod. starch	0.127 ± 0.0047^{3}b

Measurements are triplicates ± standard deviation. Different letters within the same columns, referring to the Tukey test, show statistically significant differences (p≤0.05). Spray drying input conditions were set at 150 °C for inlet air temperature, 2 L.h^{-1} for feed flow rate, 2 m^{3}. min^{-1} for blower flow rate, 30 L.min^{-1} for compressed air flow rate, and 4 bar for atomization pressure.

Statistical treatment revealed non-negligible differences in water activity between the evaluations in the sample equivalent to the maltodextrin and gum arabic and the sample prepared with modified starch as the carrier agent, according to Tukey for p≤0.05. A water activity level of less than 0.6 (being significantly higher than the averages found for the parameters in this study), according to (Mohammed; Elsheikh; Tawfik, 2018), is insufficient to support microbiological growth of known pathogens. Therefore, all three goat's milk powders carrier agent configurations were not sustainable as vehicles for the multiplication of microorganisms.

Table 5 below shows humidity, in percentage terms, of the spray dried powders obtained in this study.

3.4 Water content (%)

Table 5 – Water content (%) in spray dried goat's milk

Carrier agent	Water content (%)
Maltodextrin	2.61 ± 0.0950[a]
Maltodextrin, gum arabic	2.57 ± 0.14[a]
Mod. starch	2.08 ± 0.287[b]

Measurements are triplicates ± standard deviation. Different letters within the same columns, referring to the Tukey test, show statistically significant differences ($p \leq 0.05$). Spray drying input conditions were set at 150 °C for inlet air temperature, 2 $L.h^{-1}$ for feed flow rate, 2 m^3. min^{-1} for blower flow rate, 30 $L.min^{-1}$ for compressed air flow rate, and 4 bar for atomization pressure.

The moisture content range of the three powders was from 2.08 to 2.61%, with the highest variation observed in the dry blend of fresh goat's milk and maltodextrin. Fonseca *et al*. (2011), in their analytical study of spray drying of goat's milk using different concentrations of pea protein as microencapsulation agent, found a range between 2.5 and 2.8% of water content. Silva (2014) found, for a similar study, a higher range, residing between 6.5% and 7.06% of water content in goat's milk. The measurements had, according to the statistical analysis, non-significant differences, keeping all the parameters equal, between maltodextrin and maltodextrin-gum Arabic. Therefore, no carrier agent impact on the final water content measurement was observed ($p>0.05$) in this pair. The modified starch microencapsulated sample, however, was revealed to contain diminished water content.

3.5 Ash content

The ash content of the spray dried samples varied from 1.64 to 2.63% as shown in Table 6:

Table 6 – Ash content (%) in spray dried goat's milk

Carrier agent	Ash content (%)
Maltodextrin	1.64 ± 0.708[a]
Maltodextrin, gum arabic	2.63 ± 0.0531[a]
Mod. starch	1.76 ± 0.0638[a]

Measurements are triplicates ± standard deviation. Different letters within the same columns, referring to the Tukey test, show statistically significant differences ($p \leq 0.05$). Spray drying input conditions were set at 150 °C for inlet air temperature, 2 $L.h^{-1}$ for feed flow rate, 2 m^3. min^{-1} for blower flow rate, 30 $L.min^{-1}$ for compressed air flow rate, and 4 bar for atomization pressure.

A negligible impact was found between the carrier agent configurations on the ash content, maintaining statistical analysis parameters. The magnitude of ashes was found to reside well above the minimum required of 0.7% for any varieties of powdered milk, as established in the Normative Instruction no. 37 of the competent secretariat of the Ministry of Agriculture and Livestock, which is responsible for regulating the quality standards of dairy products for human consumption. Silva (2014), using analogous methodological practices, found a higher percentage of ash in goat's milk: 5.9%. As described by Nielsen (2010), depending on the magnitude of sugar and fat content in food, slower drying methods such as water baths or infrared irradiation are correlated with higher product ash content measurements.

3.6 Solubility (%)

The solubility analysis of the solutions atomized with three configurations of carriers led to the data presented in Table 7. A mean average of 91.9% was found between the setups, consistent with the study of (Yaakub; Zaini; Xiang, 2019), which showed a statistical insignificance between temperature variations on solubilities measured between 85.24 and 94.09%, that is, the percentage of solids homogeneously solubilized in a water sample, keeping the alluded temperature constant.

Table 7 – Water solubility index (%) of spray dried goat's milk

Carrier agent	Solubility
Maltodextrin	90.0%
Maltodextrin, gum arabic	94.1%
Mod. starch	91.5%

Spray drying input conditions were set at 150 °C for inlet air temperature, 2 $L.h^{-1}$ for feed flow rate, 2 $m^3. min^{-1}$ for blower flow rate, 30 $L.min^{-1}$ for compressed air flow rate, and 4 bar for atomization pressure.

For the spray drying process of functional goat's milk encapsulated by a mass quota of 12.10 % maltodextrin carried out by (Nisa; Ansori; Mubarok, 2025), a water solubility index of 95.55 % was determined for the resulting powder.

3.7 Milk reconstitution properties

To measure the preservation of the goat's milk characteristics, the reconstitution volume was stirred with a sample of spray dried goat's milk, generating the data shown in Table 8:

Table 8 – Acidity and refractometry of reconstituted powdered goat's milk

Carrier agent	pH	ºBx
Maltodextrin	6.24 ± 0.0252^{a}	11.2 ± 0.577^{a}
Maltodextrin, gum arabic	6.27 ± 0.0208^{a}	10.6 ± 0.681^{a}
Mod. starch	5.83 ± 0.0551^{b}	10.0 ± 0.100^{a}

Measurements are triplicates ± standard deviation. Different letters within the same columns, referring to the Tukey test, show statistically significant differences ($p \leq 0.05$). Spray drying input conditions were set at 150 °C for inlet air temperature, 2 $L.h^{-1}$ for feed flow rate, 2 $m^3.\ min^{-1}$ for blower flow rate, 30 $L.min^{-1}$ for compressed air flow rate, and 4 bar for atomization pressure.

The degree of acidity varied between 5.83 and 6.27 and the refractometric index between 10.0 to 11.2. A slim increase in acidity and maintenance of the refractive index is observed in comparison with pure samples of goat's milk, which had a mean pH of 6.49 and a mean ºBrix of 11.22. Additionally, the spray-dried powders dissolved easily in distilled water, with no visible presence of granular material remaining on the walls of the glass beakers.

The pH of the reconstitution developed from the modified starch sample and the other two were determined to be statistically different, higher in acidity; the refractometric index was not significantly altered by the choice of microencapsulation agent at the concentrations analyzed.

Reddy *et al*. (2014) found, for reconstituted spray dried Osmanabadi goat's milk, additionally from the observation that the properties of wettability and dispersibility were affected statistically by the concentration of solids, a solubility index ranging between 97.1 and 99.2%.

3.7 Conservation of water activity and water content (%)

Water activity and water content were measured, after 30 days in storage, to measure the conservation properties relevant to the spray dried milk. The results, along with, for comparison purposes, source water content and water activity measurements are distributed along Table 9:

Table 9 – Comparison of water content and activity in spray dried powdered goat's milk after 30 days in storage

Carrier agent	Powdered goat's milk		Stored (30 days) powdered goat's milk	
	a_w	Water content (%)	a_w	Water content (%)
Maltodextrin	0.137 ± 0.0100[ab]	2.61 ± 0.0950[a]	0.177 ± 0.0151[a]	2.93 ± 0.164[a]
Maltodextrin, gum arabic	0.189 ± 0.0376[a]	4.54 ± 3.41[a]	0.153 ± 0.00231[b]	2.72 ± 0.302[ab]
Mod. starch	0.127 ± 0.00473[b]	2.08 ± 0.287[a]	0.116 ± 0.00346[c]	2.23 ±0.205[b]

Measurements are triplicates ± standard deviation. Different letters within the same columns, referring to the Tukey test, show statistically significant differences ($p \leq 0.05$). Spray drying input conditions were set at 150 °C for inlet air temperature, 2 $L.h^{-1}$ for feed flow rate, 2 $m^3.\ min^{-1}$ for blower flow rate, 30 $L.min^{-1}$ for compressed air flow rate, and 4 bar for atomization pressure.

For the thermodynamic property of water activity, a range of 0.116 to 0.177 was found and a concentration of 2.23 to 2.93% water was observed, a slight increase compared to the data shown in Tables 4 and 5, obtained immediately after the drying step. Significant statistical differences were found between all three configurations of carrier agent for $\mathbf{a_w}$ ($p \leq 0.05$) and two distinct groups for water content; it was ascertained that the capacity for conservation is higher when modified starch is utilized as a carrier agent in spray drying of goat's milk. In addition, statistical indifference ($p > 0.05$) was found for water content between the maltodextrin-gum arabic and the other two microencapsulation configurations.

Nunes (2019), in a storage study of dried tomato juice, atomized by spray drying, observed a decline in water activity from 0.237 to 0.170 and in water mass content from 5.632 to 4.160%.

3.8 Colorimetric study

Following the methodology, the values obtained for the colorimetric parameters are given in Table 10:

Table 10 – Colorimetric analysis of spray dried powdered goat's milk under configurations (1), (2) and (3)

Carrier agent	*Adobe® Photoshop® 19*			Linear regression			Polynomial regression		
	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*
Maltodextrin	67.0 ± 3.21[a]	1.11 ± 0.509[b]	9.89 ± 0.770[c]	77.1 ± 3.76[a]	-1.94 ± 0.587[b]	14.1 ± 0.779[c]	77.1 ± 4.06[a]	0.109 ± 0.714[b]	13.3 ± 0.849[c]
Maltodextrin, gum arabic	64.6 ± 1.26[a]	1.56 ± 0.509[b]	12.3 ± 0.882[b]	74.0 ± 1.58[a]	-1.43 ± 0.587[b]	16.5 ± 0.888[b]	74.0 ± 1.58[a]	0.733 ± 0.716[b]	16.0 ± 0.990[b]
Mod. starch	61.3 ± 4.91[a]	3.11 ± 0.509[a]	15.4 ± 0.509[a]	70.4 ± 5.73[a]	0.359 ± 0.587[a]	19.7 ± 0.514[a]	70.0 ± 6.06[a]	2.94 ± 0.728[a]	19.5 ± 0.580[a]

Measurements are triplicates ± standard deviation. Different letters within the same columns, referring to the Tukey test, show statistically significant differences ($p \leq 0.05$). Spray drying input conditions were set at 150 °C for inlet air temperature, 2 $L.h^{-1}$ for feed flow rate, 2 $m^3. min^{-1}$ for blower flow rate, 30 $L.min^{-1}$ for compressed air flow rate, and 4 bar for atomization pressure.

Overall, the spray-dried goat's milk showed a luminosity of a moderate white intensity, with yellow being the predominant color. The supplementation of a carrier agent provoked an effect, especially towards the blue-yellow coordinate: modified starch was observed to show a higher yellow intensity. The sample obtained with the maltodextrin 20DE as the sole microencapsulation agent had the lowest value of b^*, and thus, statistically the least intense yellow out of the three samples.

The maltodextrin and the maltodextrin-gum arabic configuration samples differed significantly ($p \leq 0.05$) in terms of the red-green parameter to the modified starch sample, which was more red in color; when the carrier agent was modified, non-significant changes were perceived in the lightness factor of the spray dried goat's milk powder.

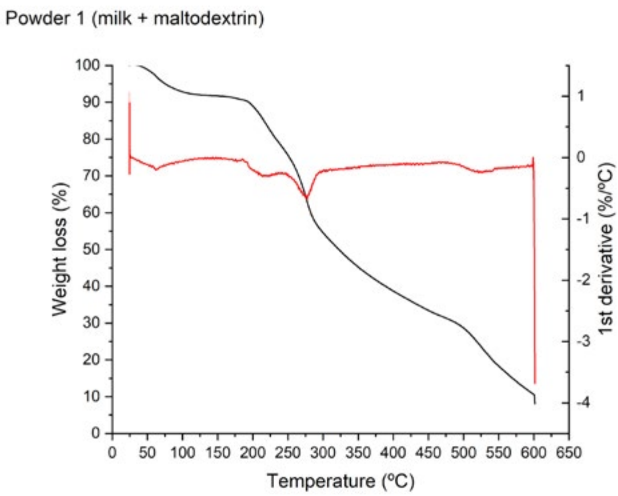
Mahdi *et al*. (2020) found that for a colorimetric study of spray dried *Citrus medica*, an insignificant relationship was found between the powder's luminosity measurement with respect to the maltodextrin, modified starch and whey protein carrier agents. Furthermore, the supplementation of whey protein in the encapsulation step was found to significantly raise the preponderance of the blue and green colors.

3.9 Thermogravimetric study

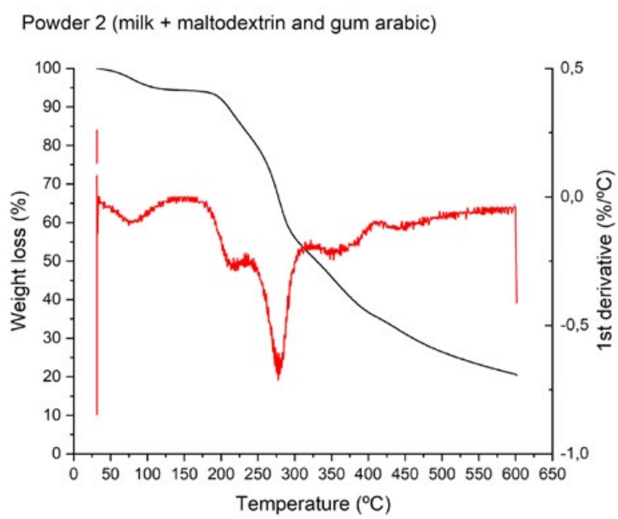
Thermal decomposition of spray dried goat's milk was found to accentuate at approximately 210 °C. For comparison purposes, the thermal behavior of each of the three configurations of microencapsulation is shown in

Figures 2 (a), (b) and (c). Significant thermogravimetric differences were verified in the second configuration of the thermal decay rate of change, with lower valleys in relation with temperature in comparison with the mixture containing maltodextrin and the sole microencapsulation agent and the modified starch, indicating a decay decreased in intensity throughout the temperature range, given similar melting stages of components in spray dried powdered goat's milk:

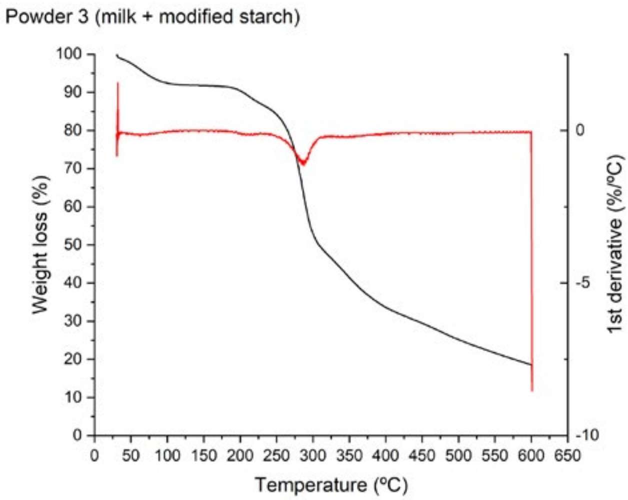
Figure 2 – Curves of thermogravimetric analysis of spray dried powders (1), (2) and (3)



(a) Goat's milk with maltodextrin



(b) Goat's milk with maltodextrin and gum arabic



(c) Goat's milk with modified starch

The study done by Ostrowska-Ligęza *et al*. (2018) found that, for the governed thermal decay of dark and milk chocolate samples, each thermal decomposition step could be assigned to chocolate starting materials due to the physicochemical nature of each unique component in biological samples, and is a useful resource for identifying fats' adulteration in chocolate products and their general quality parameters.

The spray drying technique, applied under the aforementioned process parameters and using maltodextrin, modified starch, and a gum arabic-maltrodextrin mixture as carrier agents, proved to be an effective method to preserve the physicochemical properties of goat's milk. The resulting samples exhibited values of water activity and moisture content residing well below the minimum biochemical threshold conditions required to support pathogenic microbial growth (Mohammed; Elsheikh; Tawfik, 2018), thereby meeting the standards stipulated by Brazilian food safety resolutions for powdered goat's milk. Each of the carrier agent configurations produced equivalent results in terms of ash content and refractometric index.

New strategies emerge given the logistical challenges associated with the distribution of thermosensitive food products in Brazil — limiting the expansion of goat's milk access towards broader consumer markets. These include the consolidation of supply chains, and the implementation of applied scientific knowledge into both industrial processes and in goat farming (Silva *et al*., 2025). The adoption of such proposals can enhance the goat farming sector in Paraíba and Brazil, propelling the aggregate value of goat's milk and promoting the sector's sustainable growth. Recent developments require higher conservation properties of goat's milk not only for nutrition purposes, but in other industrial segments such as cosmetics, where goat's milk was found to be an exceptional substrate for skin moisturizer creams and soaps due to the product's essential fatty acids (Silva *et al.*, 2025).

4 CONCLUSIONS

A quota of 11% m.m^{-1} of microencapsulation agent is successfully used to convert goat's milk into powder by atomization above a total solids content of 12.91%. The individual effect of maltodextrin, modified starch or a mixture of maltodextrin and gum arabic are statistically different on the physicochemical properties relevant to the powder and reconstituted milk when considering a 95% confidence interval. The choice of carrier agent therefore plays a critical role in controlling several quality parameters during the milk drying step.

Powdered milk obtained with maltodextrin-gum arabic mixture as a carrier was observed to be more soluble in distilled water and presented a finer morphology. Modified starch as a carrier revealed to produce a drier, more red and yellow in color, higher in acidity and less susceptible to pathogenic contamination when reconstituted into liquid milk, although all three encapsulation configurations were found to be effective in maintaining water activity levels below the maximum acceptable, according to Brazilian legislation on food quality parameters. However, the choice of excipient at the concentration described was demonstrated to be statistically insignificant on the ash content and the refractometric index of the restored, liquid milk parameters. The steps of thermal decay in all three configurations had indistinguishable decomposition profiles, however, at a lower rate in relation to temperature for the maltodextrin-gum arabic encapsulated spray dried powdered goat's milk.

Notwithstanding these results, which demonstrate the practicability of spray drying goat's milk using a predetermined mass quota of carrier agent configurations on a laboratory scale and within the analytical scope of major physicochemical attributes of goat's milk powder, the study is limited to a fixed set of process parameters based on the existing body of published work. Future studies ought to investigate results under a different group of parameters, including encapsulant configuration and concentration, spray dryer inlet air temperature and operating pressure, and to expand the analytical scope, assessing additional sensory attributes and storage stability over an extended period of time, providing for a more exhaustive understanding of the applicability of spray drying in science and industry.

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