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Impact of Drying Techniques and Maltodextrin as a Carrier on The Flow Properties and Reconstitution Properties of Oat “milk” Powder

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Abstract

Oat (Avena sativa) “milk” has gained popularity as a suitable alternative for individuals following vegan diets or those with lactose intolerance, owing to its appealing taste and significant health benefits. The rising demand for plant-based “milk” alternatives, however, presents challenges related to the storage stability and shelf life of liquid oat “milk”. Converting oat “milk” into powder form addresses these issues by enhancing shelf stability, improving transportability, and increasing convenience, thereby benefiting both consumers and manufacturers. This study investigates the production of oat “milk” powder using two drying techniques: spray drying and freeze drying. Maltodextrin (MD) was used as a carrier at concentrations of 0%, 5%, and 10% in both drying processes. Oat “milk” was processed using a tall-type spray dryer with a constant feed rate of 15 ml/min, an inlet temperature of 160±1°C, and an outlet temperature of 115±1°C. In parallel, vacuum freeze drying was employed to remove moisture from the frozen oat “milk” through sublimation at -60°C, maintaining the nutritional integrity of the product. The resulting powders were analyzed for flow properties, moisture content, water activity, wettability, and solubility. The water activity of the oat “milk” powder (OMP) samples ranged from 0.33 ± 0.02 to 0.6 ± 0.01, indicating microbial safety. Moisture content differed between spray-dried and freeze-dried powders, with the spray-dried powders exhibiting higher Carr’s index values. The wettability ranged from 9.33

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± 0.6 to 16.67 ± 0.6 seconds, and solubility varied from 71.34 ± 1.09% to 88.07 ± 1.10%. Additionally, the brightness of the oat "milk" powder increased with increasing maltodextrin concentration, from 80.71 ± 0.5 to 87.05 ± 1.2. These results were used to identify the optimal dehydration technique based on the physicochemical properties of the powder. The oat "milk" powder produced in this study demonstrates potential for use as a substitute for "milk" powder in vegan products, premixes, chocolates, and bakery formulations.

Abbreviations

MD	Maltodextrin
OMP	Oat "milk" powder
SDOMP	Spray dried oat "milk" powder
SDOMP 5	Spray dried oat "milk" powder with 5% maltodextrin
SDOMP 10	Spray dried oat "milk" powder with 10% maltodextrin
FDOMP	Freeze dried oat "milk" powder
FDOMP 5	Freeze dried oat "milk" powder with 5% maltodextrin
FDOMP 10	Freeze dried oat "milk" powder with 10% maltodextrin

Introduction

Dairy "milk", a nutritious and hydration-rich food, was first consumed by humans around 7000 BC but nowadays due to a genetic change enabling adults to continue producing lactase enzymes.[1] The global trend towards plant-based diets and sustainable food options has boosted the popularity of plant-based "milk" substitutes like oat "milk" due to their smooth texture, mild flavor, and nutritional benefits, driven by health, environmental sustainability, and animal welfare concerns.[2,3] Oats (Avena sativa L.) and oat derivatives are high-quality sources of soluble dietary fiber known as β-glucan,[4] rich in macronutrients[5] and phytochemicals.[6] Plant-based "milk" powders offer dairy-free alternatives, improved accessibility, and extended shelf life. They're used in various food uses. Different drying methods, like spray and freeze drying, affect powder texture and stability. The enzymatic treatment of oat "milk" with alpha-amylase not only improves its solubility and viscosity but also offers significant advantages in oat "milk" powder production. By breaking down starches, alpha-amylase enhances flow properties, reduces the bulkiness of the liquid, and prevents the gelatinization of oat "milk".[7] This is particularly beneficial during the spray drying process, as it prevents clogging of the atomizer and ensures a smoother drying process. As a result, the enzymatically treated oat "milk" produces a finer, more consistent powder. This leads to a stable, powder that is ideal for diverse applications in plant-based "milk" products. Spray drying is commonly employed to remove moisture from "milk", as it effectively preserves and stabilizes its components.[8] Freeze-drying is a beneficial method for plant-based "milk" products, offering advantages like minimal volume reduction, nutrient retention, and shape preservation.[9] Controlling the glassy condition of sugar in feed during spray drying is crucial for successful dehydration operations, as it exhibits liquid or syrup-like properties during heating.[10] The glass transition temperature of dry sucrose decreases with water content, causing particles to adhere to equipment, despite decreasing yield loss, and a significant challenge in spray drying technology.[11] To overcome challenges in drying, particles should be hardened early, and maltodextrin can act as a desiccant or dehydrator due to its carbohydrate polymer composition.[10,12] MD enhances whey protein isolate and soy protein isolate functional characteristics, increasing thermal stability and digestibility in plant-based "milk" powders with 15% maltodextrin concentration.[13] The study reveals that adding maltodextrin to green coconut pulp powder enhances density, reduces wall friction angle, and improves fluidity, impacting its processing and commercialization.[14] The study found that optimal spray drying conditions for babassu coconut "milk" include a 25% maltodextrin concentration and a 20% modified starch concentration, enhancing efficiency and powder quality.[15] This study investigates the effect of maltodextrin on different drying techniques and its impact on the properties of the resulting powder, including flow behavior, color, moisture content, and reconstitution characteristics.

Materials and Methods

The acquisition of a food-grade fungal alpha Amylase enzyme and rolled oats was made from Bioven Ingredients, India, and True Elements, India respectively. The enzyme had an activity level of 170,000 U/ml. The food-grade maltodextrin, chemicals, and reagents were procured from Sigma-Aldrich, India.

Preparation of Oat "Milk"

The oat "milk" was prepared using alpha-amylase with optimized enzymatic treatment developed by Sanika Bhokarikar, P Gurumoorthi and K. A. Athmaselvi 7 13.17% (w/w) of roasted oat flour was mixed with water to prepare oat slurry. A 9.9% (w/w) solution of fungal alpha-amylase was used after dilution 1:1000 in distilled water. The oat slurry and enzyme mixture were incubated for hydrolysis for 45 minutes at 85°C . After enzyme deactivation at 100°C , the oat "milk" was filtered through muslin cloth. Maltodextrin (MD) was incorporated into the oat "milk" at concentrations of 0%, 5%, and 10% (w/w). The "milk" was then dehydrated using both a spray dryer and a freeze dryer.

Dehydration of oat "Milk"

Oat "milk" powder (OMP) was produced using two distinct drying methods. The oat "milk" containing 0%, 5%, and 10% w/w MD was subjected to drying using a tall type spray drier manufactured by SMST Scientech. The initial temperature of the drying air was 160±1°C, while the final temperature was adjusted to 115±1°C. The settings were determined based on prior experiments. The feed rate was consistently maintained at 15±0.5 ml/min for all samples. Subsequently, all the desiccated samples were gathered in the flask of the cyclone separator. The oat "milk", which had varying concentrations of MD (0%, 5%, and 10% w/w), underwent the drying process using a vacuum freeze drier. The samples were pre-frozen in petri plates overnight at a temperature of 4 °C. In the vacuum freeze dryer (LYODEL, India), freeze-drying was carried out for 72 hours at a temperature of -60 °C. The obtained cake was pulverized using a laboratory-based grinder and sieved to produce the powder.

Moisture Content and Water Activity

The moisture content of both spray-dried and freeze-dried oat "milk" powders (OMP) was determined using the AOAC method. A 5 g sample of each dried powder was placed in a vacuum oven at 104°C for 3 hours, and the moisture content was calculated as a percentage. Additionally, 0.5 g samples of all powders were tested for water activity (aw) at room temperature using a water activity measurement device (NOVASINA AG).

Bulk Density, Tapped Density, Carr's Index, and Husner's Ratio

The bulk density (ρb) and tapped density was calculated to understand flow properties of the powder.[16]

The Carr's Index (flowability) of OMP was determined using the bulk (ρb) and tapped density (ρt) values in Eq.1. The results are presented as the Carr Index (CI) value, which is dimensionless.[17]

$$CI = \rho^t - \rho^b / \rho^t \times 100 \quad ..(1)$$

The Hausner Ratio (HR) was determined by Eq. 2 using bulk (ρb) and tapped density (ρt) values.[18]

$$HR = \rho^t / \rho^b \quad ...(2)$$

Solubility

Solubility was determined using Cano-Chauca's procedure,[19] with some modifications. One gram of OMP was added to 25 milliliters of distilled water. The mixture was homogenized using a mechanical homogenizer at 50 Hz for 5 minutes. The supernatant was then transferred to an Eppendorf tube and centrifuged at 1000 g for 5 minutes. A 20 ml aliquot of supernatant was transferred to a Petri dish and dried for 5 hours at 105 °C. The weight difference was used to calculate the solubility percentage.[20]

Wettability

Wettability was calculated by Pouring 100 mL of distilled water into a 250 mL beaker. A glass funnel on a ring stand was placed over the beaker at a height of 10 cm from the bottom to the water level. A test tube was used to obstruct the lower aperture of the funnel. The powder sample (0.1 g) was placed around the test tube and lifted while a stopwatch was started simultaneously. The time required for the powder to become fully wetted was recorded as the wettability.[16]

Colour

All samples were analyzed for color using a Hunter's colorimeter (Colour Quest XE-Di8, Hunter lab). The color values of all the samples were expressed in terms of brightness/darkness (L*), redness/greenness (a*), and yellowness/blueness (b*).

Statistical Analysis

The data was analyzed using one-way ANOVA and then Significant differences were calculated (p<0.05) by post hoc multiple pairwise Tukey test using GraphPad Software.

Table 1: Physical properties of freeze-dried and spray-dried oat "milk" powder with 0,5 and 10% maltodextrin

Properties	SDOMP	SDOMP 5	SDOMP 10	FDOMP	FDOMP 5	FDOMP 10
Bulk density (kg.m-3)	381.33±3.2[a]	324.33±5.1[b]	335.3±4.50[b]	261.6±9.81d	269.6±4.5[d]	301±3.6[c]
Tapped density (kg.m-3)	480.66±9.01[a]	386.66±3.05[b]	384±14.18[b]	292±5.13d	300.33±11.01[d]	340±10.40[c]
Carr's Index (%)	20.65±0.87[a]	16.21±0.66[b]	17.63±1.8[b]	10.50±2.5d	10.15±1.6[d]	12.24±1.3[c]
Hausner ratio	1.25±0.01[a]	1.19±0.01[b]	1.21±0.02[b]	1.11±0.02[c]	1.11±0.09[c]	1.13±0.04[d]
Water activity (aw)	0.6±0.01[a]	0.4±0.01[b]	0.34±0.02[c]	0.49±0.01[b]	0.36±0.02[c]	0.33±0.02[c]
Moisture Content (%)	3.93±0.15[a]	3.13±0.11[b]	2.7±0.2[c]	3.66±0.25[a]	2.5±0.15[d]	2.33±0.15[d]
L*	80.71±0.5[a]	82.07±0.92[b]	87.05±1.2[d]	84.15±0.09[b]	86.80±0.54[c]	86.13±0.4[c]
a*	0.26±0.03[a]	0.18±0.02[b]	0.08±0.05[c]	0.17±0.02[b]	0.15±0.02[b]	0.08±0.02[c]
b*	14.20±0.02[a]	14.03±0.15[a]	12.07±0.5[c]	13.6±0.26[b]	12.34±0.34[c]	11.52±0.10[c]

All the values are means of triplicate determination

[a-d] Significant differences (p<0.05) by post hoc multiple pairwise Tukey test.

SDOMP – Spray dried oat "milk" powder, SDOMP 5 – Spray dried oat "milk" powder with 5% maltodextrin, SDOMP 10 – Spray dried oat "milk" powder with 10% maltodextrin, FDOMP – Freeze dried oat "milk" powder, FDOMP 5 – Freeze dried oat "milk" powder with 5% maltodextrin, FDOMP 10 – Freeze dried oat "milk" powder with 10% maltodextrin

Results

The physical properties, flowability, and reconstitution characteristics of freeze-dried and spray-dried oat "milk" powder with 0.5% and 10% maltodextrin were analyzed. Table 1 presents the physical properties, Table 2 shows flowability based on Carr's index and Hausner ratio, and Table 3 details the reconstitution properties.

Table 2: Flowability of powder in the form of the Carr's index and Hausner ratio [27]

Carr's index (%)	Hausner's ratio	Flowability
0-10	1-1.11	Excellent
10-15	1.12-1.18	Good
16-20	1.19-1.25	Fair
21-25	1.26-1.34	Possible
26-31	1.35-1.45	Poor

Discussion

Effect of maltodextrin and drying method on moisture content and water activity

Since moisture content and water activity have an impact on other physical and chemical qualities, they were significant attributes of powder products. For the stability of food, they are also essential.[21] These characteristics also play a significant role in determining the stability and flowability of powder. The moisture content of the spray-dried powder ranged from 3.93 ± 0.15% to 2.70 ± 0.02%, while the moisture content of the freeze-dried powder ranged from 3.66 ± 0.25% to 2.50 ± 0.15%. As the maltodextrin (MD) concentration increased in both drying techniques, a gradual decrease in moisture content was observed. (Table 1) This aligns with the study of Ermis.[22] about freeze-dried and spray-dried hazelnut "milk" powder.[22] Previous research has demonstrated that the moisture content of various plant-based "milk" powders, such as melon seed "milk" powder, ranges from 2.1% to 2.4%[23] and drum-dried peanut-cowpea powder (2.3 to 3.7%)[21] falls within the range of 3-4%, except hempseed powder (7%).[24]

Table 3: Reconstitution properties of freeze-dried and spray-dried oat "milk" powder using 0,5 and 10% maltodextrin

Properties	SDOMP	SDOMP 5	SDOMP 10	FDOMP	FDOMP 5	FDOMP 10
Solubility %	71.34±1.09[a]	84.07±1.00[c]	85.43±1.50[c]	78.77±0.89[b]	86.67±0.59[d]	88.07±1.10[d]
Wettability (s)	15.67±0.57[a]	11.67±0.50[b]	9.5±0.90[c]	16.67±0.60[a]	11.33±0.50[b]	9.33±0.59[c]

All the values are means of triplicate determination

[a-d] Significant differences ($p<0.05$) by post hoc multiple pairwise Tukey test.

The latent heat of sublimation, which converts ice to water vapor and releases bound water molecules, leads to extended drying times and higher energy consumption in freeze-dried powders. The raw coconut "milk" powder that was dried by freeze drying had 1.19% and spray drying had a moisture content of 2.5%, while the commercial coconut "milk" powder had 3.83%.[25] Similar results are found in the case of OMP, where FDOMP with various MD concentrations has less moisture content than SDOMP.

Maltodextrin, due to its low hygroscopicity, decreases water activity and moisture content in dried powders, thereby enhancing their stability and quality. This reduction in moisture absorption is beneficial for enhancing the overall stability of the dried powder.[26] In the OMP samples, water activity decreased as the moisture content reduced. Additionally, the freeze-dried samples exhibited lower water activity compared to the spray-dried samples. Since the water activity of the OMP samples ranges from 0.34 ± 0.02 to 0.60 ± 0.01, they can be considered microbially safe, with the exception of SPOMP, which is borderline. (Table 1) This results in a decrease in moisture content, with freeze-dried samples having slightly lower moisture content compared to spray-dried samples.

Effect of Maltodextrin and Drying Method on Bulk Density and Tapped Density

Tapped density was calculated to assess the impact of spray and freeze drying on powder flowability as well as other powder properties like bulk density. The final product obtained after dehydration was classified based on key parameters such as bulk and tapping densities.[28] Bulk density and tapped density of freeze-dried ranged from 261±9.81 to 301±3.6 kg/m3 and 292±5.13 to 340±10.40 kg/m3, respectively. These values were lower than those of spray-dried OMP ranging from 381.33±3.21 to 335.3±4.50 kg/m3 and 480.66±9.01 to 384±14.18 kg/m3, respectively). The bulk densities of spray-dried oat "milk" powder (SDOMP) were higher compared to freeze-dried oat "milk" powder (FDOMP). Both drying procedures showed a decrease in bulk density when maltodextrin was added (from 0% to 10%) Maltodextrin concentration affects bulk density, porosity, and particle packing. Spray drying and freeze-drying produce compact particles while freezing results in concentrated aqueous solutions and ice crystals.

The process of freeze drying is carried out below the product's triple point, where the resulting structure is made up of pores where ice crystals formerly were, encircled by a dry matrix of precipitated chemicals and insoluble parts that were once in the solution.[29] High interparticle surface contact of spray-dried powder could be the reason. These findings are coherent with the raw coconut "milk" powder produced by spray-drying and freeze-drying.[25] Additional factors that could cause variations in bulk density values include the type of technique employed, the addition of MD, and the degree of particle porosity. Because powder porosity varies, the choice of drying technique affects powder density.[30]

Effect of Maltodextrin and Drying Method on Carr's Index, and Hausner's Ratio

The values of the Carr index and Hausner ratio were calculated to assess the powders' flow characteristics. As per Carr (1965) and Hausner (1967) Hausner's ratio and Carr's index are linked with flow characteristics.[17,31] The Carr index, a commonly used metric for evaluating powder flow, indicates the flowability characteristics of the powders (Table 1) Hausner's ratio of spray-dried powders ranged from 1.19±0.01 to 1.25±0.01 which represents fair to good flowability while freeze-dried powders ranged from 1.11±0.02 to 1.13±0.04 resulting in Excellent to good flowability. (Table 1) (Table 2) Carr Index values represent the flowability properties of powder Spray-dried powder's Carr's index ranged from 16.21±0.66% to 20.65±0.87%, while freeze-dried powder's ranged from 12.24±1.3 to 10.15±1.6. The Carr's Index, a measure of flowability, was higher in the spray-dried samples, suggesting that the flow characteristics of these powders were inferior to those of the freeze-dried powders. Maltodextrin improved flowability in both drying techniques, reducing stickiness and cohesion. Spray-dried powders have a higher Carr's Index, indicating greater cohesion due to increased volume and peak densities. Freeze-drying produces finer particles, increasing surface area and allowing higher interaction of surface cohesive forces, resulting in cohesive or bad flow.[32,33]

All oat "milk" powders that have undergone spray-drying, regardless of the percentage of maltodextrin, are classified as having "Fair" flowability. Spray-dryed oat "milk" powders have "Fair" flowability, despite maltodextrin content. This makes processing and packaging difficult. Spray-dried powders have a denser structure, fewer particles, and a higher Carr's Index and Hausner Ratio. Freeze-dried powders, with 0% and 5% maltodextrin, have improved flowability due to their porous structure, allowing unrestricted particle movement.

The study reveals that adding 5% maltodextrin to oat "milk" powders improves flowability and reduces the Carr index. However, adding 10% maltodextrin may cause moisture absorption and particle clumping, hindering the flow. The findings highlight the importance of considering processing techniques and additives in powder development to improve flow behavior.[34] Anti-caking chemicals like calcium stearate, silicon dioxide, sodium aluminum silicate, tricalcium phosphate, and calcium silicate are also used to enhance flowability.

Effect of Maltodextrin and Drying Method on Solubility

One of the powder's most crucial reconstitution qualities was its ability to blend with water i.e. solubility.[35] OMP's microstructure, directly linked to water solubility, could enhance market acceptance when used in drinks, as amorphous powders are highly soluble in water.[19] Increased quantities of maltodextrin have been associated with better solubility, leading to the production of powders with low water activity, high water solubility index, and enhanced wettability. These qualities make them highly suitable for a wide range of food applications.[36] In both drying methods, 10 % MD gave very good solubility of 85.43±1.00% and 88.07±1.10 in SPOMP 10 and FDOMP 10 respectively.

The solubility was enhanced by the use of maltodextrin and generally exhibited higher levels in freeze-dried powders as compared to spray-dried powders. Maltodextrin enhances solubility by forming a less crystalline arrangement, hence facilitating its dissolution in water. Due to its ability to maintain molecular structures, the freeze-drying process generally leads to increased solubility. Spray-dried OMP without MD had the lowest solubility of 71.34±% with a high moisture content. (Table 3) 2.1% Moisture content is also associated with melon seed "milk" powder powders' high solubility of 99%. The non-sticky quality of the powder seems to be related to low moisture content.[23,37]and fast rehydration.[38] Oat "milk" powder achieves similar results. The addition of maltodextrin (MD) reduced the moisture content, which subsequently increased the solubility of the oat "milk" powder in water.

Effect of Maltodextrin and Drying Method on Wettability

The powders' wettability was a crucial component in the re-dispersing procedure, and the wetting time was utilized to examine the product's immediate behavior.[39] Various food applications require specific functions such as sinkability or wettability, which refers to the powders' capacity to float on the water surface.[40] Powder's initial solubility begins with complete wetting upon water contact. Smaller particles reduce reconstitution due to surface tension, creating a viscous border impeding capillary flow.[41]

The wettability of freeze-dried and spray-dried oat "milk" powders lack significance differences due to their similar surface properties. (Table 3) The initial interaction with water is determined by the powder's surface area, particle size, and hydrophobicity. However, the addition of maltodextrin significantly impacts wettability by modifying the powder's surface characteristics. Maltodextrin, a hydrophilic compound, enhances the attraction between powder particles and water, resulting in a shorter wetting time. Samples with higher maltodextrin concentration show faster wettability due to its hydrophilic properties. The wettability of oat "milk" powder was observed to be significantly lower, with values ranging from 9.33± to 16.67±0.6 seconds across both spray-dried and freeze-dried samples, depending on the maltodextrin concentration.

The spray-dried soy"milk" powder's wettability index ranged widely from 22 to 1100 seconds.[42] In another study conducted on blackberry powders produced using spray drying had a wettability range of 82 to 134 seconds.[43,44] Ortega Rivas[28,45] suggested that tiny particles with a high surface area to mass ratio may not be wetted. Individually, they may aggregate and share a moistened surface layer. This layer decreases the rate of water infiltration into the particle cluster. Therefore, the duration for the sample to submerge in the water has been extended[45,42,43] The explanation offered by Ortega Rivas[28,45] does not appear to be a major factor in this study. The shorter wettability times in the oat "milk" powders suggest that either the particle size or surface properties facilitate rapid water absorption, likely due to the hydrophilic nature of maltodextrin.

Effect of Maltodextrin and Drying Method on Colour of the Oat "Milk" Powders

Product color is a crucial parameter influenced by several factors, including the color of the raw material, the type and concentration of carriers, and the drying air temperature.[46] The brightness of oat "milk" powder exhibited enhancement with increasing concentration of MD, ranging from a minimum value of 80.71±0.5 to a maximum value of 87.05±1.2 which supports the study conducted by 22 The a* values of all the samples were insignificant and below 0.2. The b* values declined as the MD concentration and L* increased, indicating a decrease in the yellowness of the samples. Furthermore, the freeze-dried OMP powder exhibited a consistently high level of brightness across all samples, ranging from 84.15±0.09 to 86.80±0.54, in comparison to the spray-dried oat "milk" powder. Among all the samples, FDOMP 10 had the lowest yellowness, measuring 11.52±0.10. Lightness (L) increased with maltodextrin concentration in both drying methods, indicating a lighter color. Freeze-dried samples were generally lighter. Both drying methods showed a decrease in a* value with increasing maltodextrin, indicating a shift towards a greener hue. b* value decreased with maltodextrin concentration, signifying a reduction in the yellow color intensity. Technological parameters, such as temperature, can affect the color of powdered "milk" products. These parameters are responsible for the formation of Maillard reactions, which are non-enzymatic browning reactions that commonly occur in thermally processed "milk" between proteins and reducing sugars.[47] Therefore, the freeze-dried OMP exhibited a superior colour consistency compared to the spray-dried OMP. Consumers are likely to readily acknowledge the high level of brightness exhibited by OMP.

Conclusion

Oat "milk" is made after enzymatic treatment was mixed with Maltodextrin (MD). The oat "milk" was dehydrated using spray and freeze dryers. The water activity of OMP samples varied between 0.33±0.02 and 0.6±0.01, making it microbially safe. MD addition reduced Carr's index and improved flowability. Freeze-drying produced finer particles, leading to better flow. With an increase in MD concentration, there was a decrease in wettability and a decrease in cluster formation during the drying process. Spray-dried OMP exhibited spherical particles and aggregation, while freeze-dried OMP had flaky particles. The use of MD also decreased the agglomeration and clustering of particles, resulting in enhanced powder flow characteristics. Among the various formulations, FDOMP 5, which used 5% MD, exhibited the best overall performance in terms of particle size, flowability, and reconstitution properties. There was no statistically significant difference between FDOMP 5 and FDOMP 10 in several analyses, suggesting that using excessive MD did not provide additional benefits. Therefore, the FDOMP 5 formulation is recommended as the optimal choice for producing oat "milk" powder. This plant-based "milk" powder can be utilized as a "milk" substitute in various plant-based compositions, offering a high-quality alternative with excellent flowability and reconstitution properties.

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Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

The data supporting the findings of this study are available within the article and its supplementary materials. Additional data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration

This research does not involve any clinical trials.

Permission to Reproduce Material from Other Sources

Not Applicable.

Author Contributions

- **Sanika Bhokarikar:** Conceptualization, Methodology, Data Collection, Writing – Original Draft.
- **Parameswaran Gurumoorthi:** Supervision, Project Administration, Writing – Review & Editing.
- **Kathirvelpillai Athmanathan Athmaselvi:** Data Analysis, Visualization, Writing – Review & Editing.

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