RESEARCH ON THE INFLUENCE OF GRINDING TIME ON THE PARTICLE SIZE DISTRIBUTION WHEN OBTAINING ROSEHIPS POWDER
/
CERCETĂRI PRIVIND INFLUENȚA TIMPULUI DE MĂCINARE ASUPRA DISTRIBUȚIEI DIMENSIUNII PARTICULELOR LA OBȚINEREA PULBERII DE MĂCEȘE

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ABSTRACT
This study evaluates the influence of grinding time on the particle size distribution of rosehip powder. A universal mill based on the cutting principle was used, equipped with four sieves with different mesh sizes (0.2 mm, 0.5 mm, 1 mm, and 4 mm). The grinding durations were set at 30 seconds, 60 seconds, 90 seconds, 120 seconds, and 150 seconds. Each grinding stage was followed by particle separation using a set of sieves to determine the particle size distribution. The results indicated that both the grinding duration and the mesh size of the sieves significantly impacted the particle size distribution. The 0.5 mm sieve associated with a grinding time of 90 seconds provides an optimal balance between achieving a reduced average particle diameter, high specific surface area, and energy efficiency. These findings have important implications for the production and quality control of rosehips powder in various applications, including food, nutraceutical, and pharmaceutical products. Understanding the granulometric behavior of rosehip powder can help improve the solubility, stability, and bioavailability of the product. This research establishes the groundwork for further studies focused on optimizing grinding processes and developing rosehip powder products with customized particle size distributions to meet the specific demands of various industries.

REZUMAT
Acesta lucrare evaluează influența timpului de măcinare asupra distribuției dimensiunii particulelor pulberii de măceșe. A fost utilizată o moară universală bazată pe principiul de tăiere, echipată cu patru site cu dimensiuni diferite ale ochiurilor (0.2 mm,0.5 mm, 1 mm și 4 mm), iar timpii de funcționare au fost de (30 secunde, 60 secunde, 90 secunde, 120 secunde și respectiv 150 secunde). Fiecare etapă de măcinare a fost urmată de separarea particulelor printr-un set de site pentru a determina distribuția dimensiunii acestora. Rezultatele au indicat faptul că atât durata de măcinare, cât și dimensiunea ochiului sitei au avut un impact semnificativ asupra distribuției dimensiunii particulelor. Sita de 0,5 mm asociată cu un timp de măcinare de 90 de secunde oferă un echilibru optim între obținerea unui diametru mediu redus al particulelor, suprafață specifică mare și eficiență energetică. Aspectele prezentate constituie implicații importante pentru producția și controlul calității pulberii de măceșe în diverse aplicații, inclusiv în alimentație, obținerea de produse nutraceutice și farmaceutice. Înțelegerea comportamentului granulometric al pulberii de măceș poate ajuta la îmbunătățirea solubilității, stabilității și indisponibilității produsului. Această cercetare pune bazele pentru studii ulterioare privind optimizarea proceselor de măcinare și dezvoltarea produselor sub formă de pulbere de măceșe cu distribuții adaptate a dimensiunii particulelor pentru a îndeplini cerințele specifice ale industriei.

INTRODUCTION
Rosehip, or *Rosa canina L*., is a plant that is widely used in cosmetics, medicines, and nutrition. Growing wild in regions including Asia, North America, Europe, and the Middle East, it is a member of the *Rosaceae* family and belongs to the *Rosa genus*. The health-promoting qualities of rosehip are attributed to its considerable levels of bioactive substances, which include vitamins, minerals, antioxidants, and phenolic compounds (*Igual et al., 2022; Patel, 2017; Belkhelladi & Bougrine, 2024; Ghendov-Mosanu, 2020).* Rosehip is a fruit that is high in nutrients and it is considered to be of significant scientific importance.

Phenolic acids (gallic acid, ellagic acid, caffeic acid, p-coumaric acid), carotenoids (lycopene, β-carotene, zeaxanthin), anthocyanins, tocopherols (α- and β-tocopherols), tannins, and flavonoids (flavan-3-ols) are the primary bioactive components of rosehip (*Igual et al., 2021; Negrean et al., 2024; Lustrup & Winther, 2022; Peña et al., 2023; Koczka et al., 2018; Nađpal et al., 2016*).

Rosehips can be used for much more than just jams and infusions; drying the fruits and then grinding them into a powder is one of the best ways to utilize them. The obtaining of product in powder form would increase its uses as reconstituted juice or infusion, or added to breakfast, ice cream, dairy products, baked goods, smoothies, shakes, salads, snacks, and more. It could even be used to directly enhance any food with bioactive ingredients *(Igual et al., 2021)*. Rosehip powder can be consumed as capsules, which come in a variety of brands (*Götz et al., 2011*).

A patent has revealed an innovative technology for processing rosehip powder, enabling the production of particles with extremely small dimensions, which are critical for efficient integration into food and beverage products. This advanced micronization method optimizes the dispersibility and solubility of the powder, thereby ensuring superior performance in food formulations where homogeneity and fine texture are essential. Additionally, this finely milled powder enhances the stability of the final products, preventing sedimentation and offering a refined sensory experience for the consumer. The resulting powder contains no particles larger than 600 micrometers, with approximately 50% of the particles measuring between 100 and 150 micrometers. US Patent 6,024,960 to Kharazmi et al. describes how rose hips are transformed into a fine, dry powder with small particles (less than 1 mm, ideally between 0.1 and 0.5 mm). This technology is used to produce the powders HYBEN-VITAL and i-FLEX, which are used in food products and nutritional supplements. Additionally, patent US 2007/0184164 examines the use of rose hip powder with particles of 841 microns or smaller in food premixes, enriched with essential nutrients such as alpha-linolenic acid, dietary fiber, and antioxidants, demonstrating the versatility of this powder in various food formulations. The Japanese patent Kokai 2004275015 (K. Emoto, 2004) reveals the use of rose hip powder with an average particle size of less than 2 mm as a gelling agent in the production of fruit jams. The Chinese patent 101040833 (Tianjin Yumelijing Group Co., Ltd) describes a cosmetic product that incorporates rose hip pulp among other ingredients, with particle sizes varying from 5 mesh (4000 microns) to 200 mesh (90 microns). The patents discussed underscore the critical role particle size plays in the formulation of products across various industries, including food, pharmaceuticals, and cosmetics. The precise control of particle size, whether in rose hip powders used as gelling agents in fruit jams, as nutritional supplements, or as components in cosmetic products, directly influences the texture, stability, and bioavailability of the final product. This highlights the importance of selecting and processing ingredients to specific particle sizes to optimize their functional properties and efficacy in diverse applications (*Götz. et al., 2011*).

Specifications involving finer particles and stricter control over the mean particle size, or the width and cut-off of the particle size distribution, have been increasingly rigorous in recent years, especially in the food and pharmaceutical industries *(Tangirala et al., 2014; Silva et al., 2013; Shekunov et al., 2007)*. Particle-size distribution (PSD) is a mathematical function or a list of numbers that indicates the relative amount (usually expressed in mass) of particles present based on size in a powder, granular material, or particles distributed in fluid. Grain size distribution is an alternative name for PSD (*Ujam & Enebe, 2013; Bayat et al., 2015; Islam et al., 2022*). Particle size distribution is a crucial factor since it affects several product attributes, including density, flowability, compressibility, segregation, and rehydration. Nevertheless, it can be difficult to find the appropriate PSD. Accidentally modifications to the PSD, such as attrition of particles, or deliberate modifications, such as grinding, can occur downstream *(Carpin et al., 2017; Servais et al., 2002; Guo et al., 2024)*. Another product attribute that can be affected by the PSD of the powder is caking, which is the unintentional agglomeration of powder particles visible as lumps of different sizes and hardness (*Carpin et al., 2017*).

Several methods are employed to determine PSD, each suited to different types of materials and particle sizes. Common techniques include laser diffraction, dynamic light scattering (DLS), image analysis, and sieve analysis. Each method offers unique advantages and insights. For instance, laser diffraction is highly effective for a wide range of particle sizes and provides rapid results, while DLS is often used for sub-micron particles in colloidal suspensions (*Li et al., 2005; Lyu et al., 2020; Fuaâ & Tajdari, 2011; Nijhu et al, 2024; Ma S. et al., 2024)*. Sieve analysis, one of the oldest and most straightforward methods, remains widely used (*Dodds, 2024*). However, for a more precise analysis of fine particles or for samples that may cause sieve clogging, more advanced alternative methods may be necessary.

This technique involves passing the powder through a series of sieves with progressively smaller mesh sizes, allowing for the separation and quantification of particles based on size. When analyzing particle size distribution (PSD) using sieve analysis, the method offers simplicity, cost-effectiveness, and the ability to handle large sample volumes. However, sieve analysis has limitations, especially with finer particles, where problems such as agglomeration and reduced separation efficiency can lead to inaccuracies (*Kroetsch & Wang, 2008; Fahrenholz et al., 2010; Patwa et al., 2010; Liu et al., 2023)*. Additional advantages and limitations of sieve analysis are illustrated in Figure 1, which provides a detailed visual representation of the method's overall effectiveness. (*Igathinathane et al., 2009; Sonaye S. Y., & Baxi, 2012*).

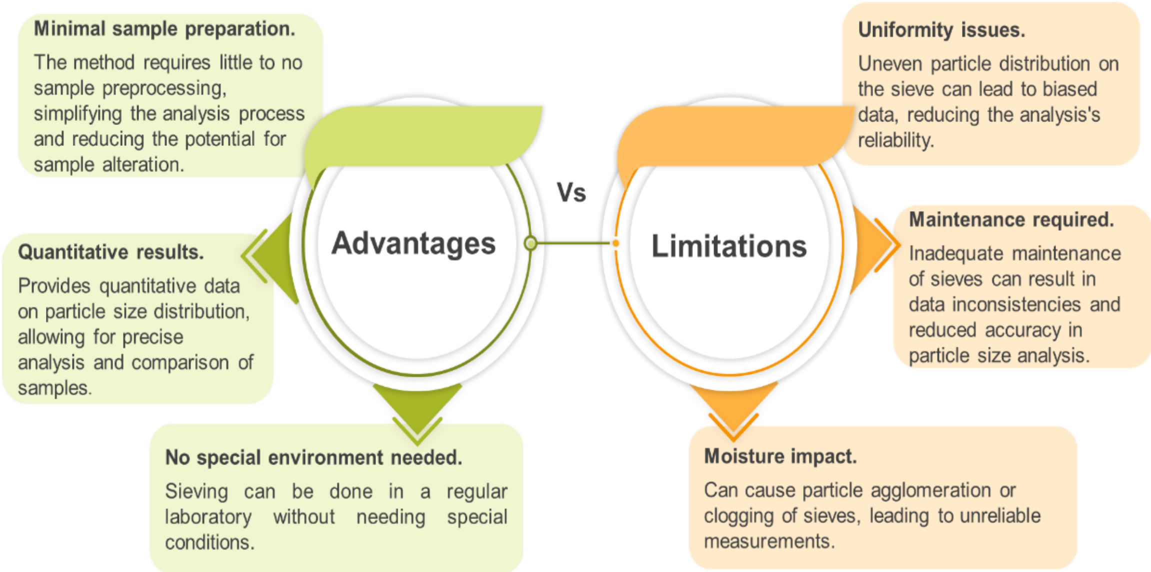

Fig. 1 - Overview of advantages and limitations in particle size distribution analysis using the sieving method
(*Igathinathane et al., 2009; Sonaye & Baxi, 2012*)

Grinding time significantly influences the particle size distribution of rosehip powder. As the grinding time increases, larger particles are broken down into smaller ones, leading to a finer distribution. Initially, the reduction in particle size is rapid, but over time, the rate of size reduction slows as the particles become smaller and harder to break down further. Extended grinding can also lead to the agglomeration of fine particles due to increased surface energy, which may affect the uniformity of the particle size distribution. Therefore, optimizing grinding time is crucial for achieving the desired particle size distribution (*Liu et al., 2016; Kumar et al., 2021; Liu et al., 2022; Shuhua et al., 2021; Hanumanthappa et al., 2020).*

The objectives of this study are to analyze the effect of varying grinding times on the particle size distribution of rosehips powder and to determine the optimal grinding time needed to achieve the desired fineness and uniformity. Additionally, the study aims to investigate the relationship between prolonged grinding and the potential for particle agglomeration. By addressing these objectives, the study aims to provide valuable insights into the grinding process for rosehips powder, helping to optimize the production parameters for achieving a high-quality product.

MATERIALS AND METHODS

Rosehip fruits of the *Rosa canina* variety were carefully hand-picked from a wooded area in Vâlcea County at the beginning of September. The fruits were fully ripe, exhibiting a vibrant light red color, and were meticulously selected to be free of mold, blemishes, and other impurities. After harvesting, the rosehips were thoroughly washed and then dried in a laboratory-controlled environment at 40°C until they reached a moisture content of 5%. This drying process was crucial to prevent microbial growth and ensure long-term storage stability. The dried rosehips were then stored in moisture-proof polyethylene bags and kept in a refrigerator at 5°C to preserve their moisture content and overall quality for subsequent studies. For the experimental tests, a total of 600 grams of dried rosehips were prepared, ensuring an ample supply for repeated trials and consistent results. From this batch, a sample size of 30 grams was selected for each individual experiment. The whole fruits, including peel, pulp, and seeds, were subjected to the grinding process to obtain a powder that retains the full nutritional value of the rosehip.

This approach was taken to ensure that the powder captured the complete range of natural compounds present in each component of the fruit, maximizing its potential health benefits and functional properties. Additionally, the inclusion of seeds and peel in the grinding process contributes to a richer profile of bioactive compounds, such as antioxidants, vitamins, and fatty acids, which are essential for the comprehensive evaluation of the powder's quality and efficacy in various applications. The five key experimental steps and corresponding equipment were illustrated in Figure 2.

Fig. 2 - Experimental protocol for particle size characterization as a function of grinding time and milling sieve mesh dimensions

Grinding process was carried out using a Fritsch Pulverisette 19 mill, specifically designed for processing hard materials. This mill operates on the cutting principle, where the material is finely ground through the interaction between the rotor's cutting edges and the stationary knives within the grinding chamber. The mill can present a maximum feed size of 70 x 80 mm, boasts a flow rate of up to 60 liters per hour, and operates at a rotor speed of 2800 rpm. The design of the grinding chamber is optimized for efficiency, featuring smooth inner walls that prevent the formation of dead spaces, which also simplifies and accelerates the cleaning process. The mill is engineered for easy maintenance; the rotor and sieve cassette can be quickly detached for thorough cleaning. The rotor itself is constructed from hardened stainless steel and is equipped with four straight cutting edges aligned parallel to the stationary knives. These knives feature two cutting edges and can be reversed when necessary, effectively doubling the operational lifespan of the rotor.

Material was introduced into the grinding chamber, where it was allowed to flow freely and was shredded as it passed between the cutting edges of the rotor and the stationary blades. The final particle size was controlled using four different sieve cassettes, each with cells of varying dimensions: 4 mm, 1 mm, 0.5 mm, and 0.2 mm. Grinding durations for each sieve size were set at 30, 60, 90, 120, and 150 seconds, respectively. Time was accurately measured using a precise stopwatch. Once the material reached the desired fineness, the particles passed through the sieve openings and were collected in a designated vessel.

The sieves had trapezoidal perforations for the 0.2 mm, 0.5 mm, and 1 mm sizes, which provided an additional shredding effect due to the increased shear forces compared to the square perforations used of the 4 mm sieve. This design improved grinding efficiency by facilitating additional size reduction of the material before it passed through the sieve and into the collection vessel.

The particle size distribution analysis was conducted using the Analysette 3 Spartan Vertical Vibrating Laboratory Sieve Shaker (Fritsch, Idar-Oberstein, Germany), a high-precision instrument designed for accurate particle separation and classification based on size. This equipment operates on the principle of vertical vibration, which ensures that the material is evenly distributed across the sieve surfaces. This even distribution allows particles to pass efficiently through a series of sieves arranged in a stack, where each sieve has a progressively smaller mesh size from top to bottom. Process begins by placing the sample in the top sieve, which has the largest mesh size. The shaker then subjects the stack of sieves to mechanical agitation, causing the particles to move through the sieves. As the particles travel downward, they are separated according to their size: larger particles are retained on the upper sieves, while smaller particles pass through to the lower ones. By collecting and weighing the material retained on each sieve, a detailed particle size distribution profile is generated. This profile is crucial for assessing the granulometry of the rosehip powder, as it provides insight into the proportion of particles within specific size ranges. The equipment's adjustable vibration settings further enhance the accuracy of the sieving process, ensuring consistent and reliable results across different samples.

The average particle size (d_m) is typically calculated using a mathematical formula based on the distribution of particle sizes in a sample. One common method is the weighted arithmetic mean size, which can be expressed as follow (*Ionescu et al., 2024*):

$$d_m = \frac{\sum a_i\,(\%) \times d_i}{100}\ (mm) \tag{1}$$

Specific surface area (S_{sm}) of a set of particles is a critical parameter that describes the total surface area of particles per unit mass or volume. This measurement is particularly useful in powder technology, as it significantly influences the reactivity, dissolution rate, and overall stability of materials in powder form, which is especially important in the food and pharmaceutical industries (*Ionescu et al., 2024*).

$$S_{sm} = \frac{6}{100 \times \rho} \sum_{di}^{n+1} \frac{a_i}{d_i} \left(\frac{m^2}{kg}\right) \tag{2}$$

where:

d_m-average particle diameter (mm); a_i- percentage of material with a size between dimensions l_i and l_{i+1} of the adjacent sieves (mm); d_i-average particle size of fraction (mm), ρ- density of the particle material (kg/m³); S_{sm}- specific surface area (m²/kg);

To obtain the trend lines of the average particle diameter as a function of grinding time, as well as the specific surface area as a function of grinding time, for all four sieves used during the grinding process of dried rose hips, a statistical package Microsoft Excel Version 2406 64-bit was used. This methodical approach facilitated a comprehensive analysis of the grinding kinetics, revealing distinct trends for each sieve type, which were essential for understanding how grinding parameters affect particle morphology. Consequently, this facilitated a deeper insight into the interplay between particle size distribution and grinding duration, guiding the optimization of grinding conditions.

RESULTS

Within this section are presented and analyzed the experimental results obtained from grinding the material using sieves of different sizes (0.2 mm, 0.5 mm, 1 mm, and 4 mm) and for various grinding durations. The purpose of this analysis is to highlight how grinding time influences the *average particle diameter* and to identify specific behaviors for each sieve size, including possible particle agglomeration phenomena at extended grinding times. Average diameter variation graph (Figure 3) as a function of grinding time is used to illustrate the trends observed for each sieve. Each trend lines is described in detail using regression equations to quantify the correlation between the analyzed variables. The coefficient of determination (R^2) values are also discussed to evaluate the degree of model fit to the experimental data and to provide a clear picture of the accuracy and relevance of the obtained results.

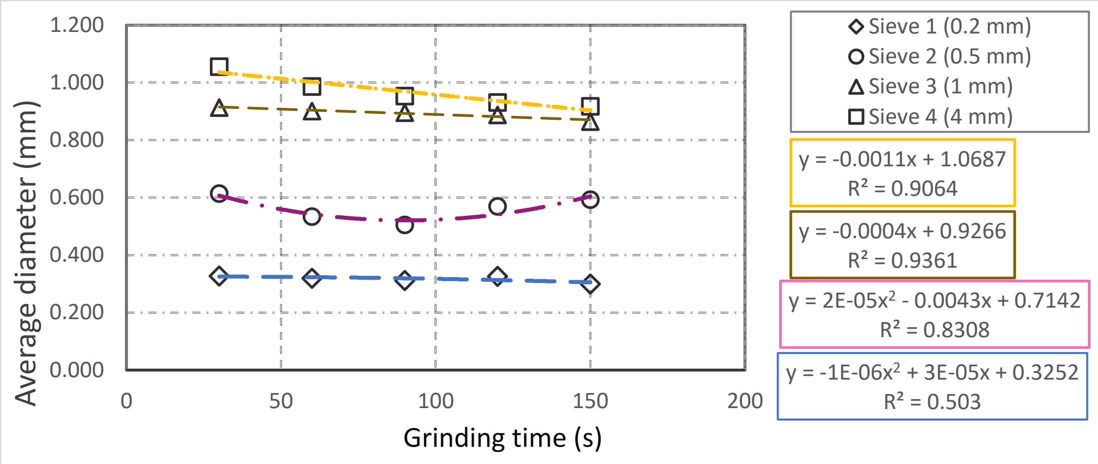

Fig. 3 - Variation of average particle diameter with grinding time for different sieve sizes

For the finest fraction passing through Sieve 1 (0.2 mm), the polynomial regression of second degree exhibits a low coefficient of determination (R^2 = 0.503), indicating substantial variability and limited predictive accuracy. This curve suggests a dynamic equilibrium between particle fragmentation and agglomeration phenomena. As grinding continues, particle size reduction approaches a physical limit dictated by material properties and grinding efficiency, while concurrent agglomeration or reaggregation processes lead to slight increases in effective particle diameter.

The particle size evolution for the fraction passing through Sieve 2 (0.5 mm) is described by the same second-degree polynomial regression with a coefficient of determination R=0.831. The positive quadratic and negative linear coefficients define a concave upward curve, indicating an initial decrease in mean particle diameter during grinding, followed by a slight increase at extended grinding times.

Analyzing the polynomial regression equations for Sieves 1 and 2 (with aperture sizes of 0.2 mm and 0.5 mm, respectively), it can be observed that the coefficient of the quadratic term (x^2) is very small. This suggests that a linear relationship between the parameters, mean particle diameter and grinding time, can still be considered. To support this assumption, linear regression equations were also determined: for Sieve 1, $y=-0.0002x+0.3322$ with $R^2=0.4764$, and for Sieve 2, $y=-2\times10^{-5}x+0.5652$, with $R^2=0.0005$. However, the coefficient of determination (R^2) remains relatively low when applying a linear regression model, indicating a limited explanatory power despite the apparent linear trend.

Furthermore, the linear trend line for Sieve 3 (1 mm), with a coefficient of determination R^2=0.9361, demonstrates a strong and well-defined correlation between grinding time and the reduction in average particle size. This indicates that as grinding time increases, particle size consistently and predictably decreases. High coefficient of determination suggests that the linear model accounts for nearly 94% of the variation in particle size. The constant reduction in size implies an efficient grinding process that does not result in significant particle agglomeration, indicating that the particles do not become small enough to cause agglomeration issues.

The linear trend line for sieve 4 (4 mm), with a coefficient of determination of R^2=0.9064, indicates a clear and strong correlation between grinding time and the reduction in average particle size. This suggests that as the grinding time increases, there is a continuous fragmentation of larger particles into smaller ones. The high value of R^2 reflects a robust relationship, meaning that the model effectively explains the variation in particle size. Although the particles are consistently broken down into smaller sizes, they do not reach dimensions small enough to cause significant agglomeration. Thus, the grinding process is effective in reducing particle size without leading to problems associated with particle clustering.

The varying behavior of particles based on sieve size highlights the complexity of the grinding process. For fine particles (0.2 mm and 0.5 mm), extending the grinding time does not necessarily result in a continuous reduction in size due to the phenomenon of agglomeration. Optimizing the process to achieve a specific particle size distribution requires careful consideration of the dynamic balance between grinding and agglomeration, especially for finer particles. Controlling parameters such as moisture, temperature, or grinding energy is crucial for managing this balance. Prolonged grinding can heat the material, affecting its properties and potentially influencing its grinding behavior. Even though the same amount (30 g) was used for each experiment, the exact composition of the rosehip samples may vary from batch to batch, adding another layer of complexity to the process.

The graph in Figure 4 presents a detailed analysis of how sieve mesh size and sieving time affect the average particle diameter. Each set of columns in the graph represents the average diameter of particles (in millimeters) that have passed through sieves of different sizes (0.2 mm, 0.5 mm, 1 mm, and 4 mm) at different time intervals (30, 60, 90, 120, and 150 seconds). The mean particle diameter of ground rosehip increases linearly with the increase in sieve aperture size.

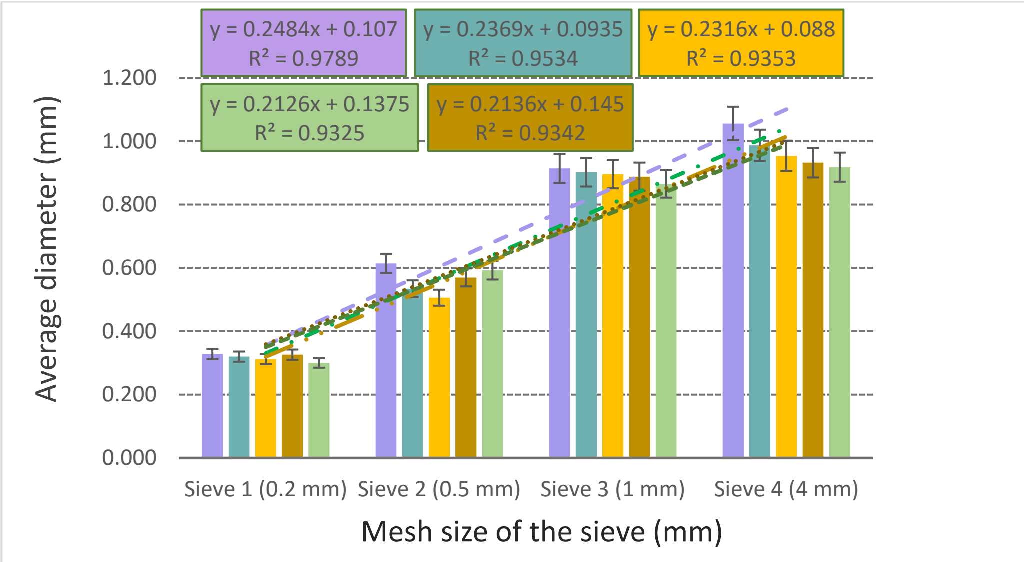

Fig. 4 - The relationship between sieve mesh size and particle diameter evolution based on grinding time

Analysis of sieve 1, which has a nominal size of 0.2 mm, shows that the average particle diameter is approximately 0.3 mm. This indicates a notable deviation from the nominal sieve size, suggesting that the resulting particles are larger than the specified dimension. The minor variations in particle size related to grinding time emphasize that, although the grinding process affects particle size, it does not consistently achieve the precise nominal sieve size.

Also, for sieve 2, with a nominal size of 0.5 mm, the average particle diameter increases notably, ranging from approximately 0.5 to 0.6 mm. Additionally, there is a greater variability in particle size relative to the grinding time, with a general trend showing that particles tend to be smaller with longer grinding durations. This suggests that extended grinding periods can reduce the size of the particles, but there remains a notable deviation from the nominal sieve size.

Additionally, for sieve 3, with a nominal size of 1 mm, the average particle diameter increases substantially, reaching values between 0.85 and 1.05 mm. The variation in particle size related to the grinding time is more pronounced, showing a clear trend of decreasing average diameter as the grinding duration increases. This indicates that while the sieve is designed to retain particles up to 1 mm, the actual particle sizes can vary, with longer grinding times resulting in smaller average particle diameters.

In the same way, for sieve 4, with a nominal size of 4 mm, the average particle diameter reaches its highest values, ranging between 0.9 and 1.1 mm. The most significant variation in particle size is observed based on grinding time, with a notable decrease in the average diameter as the grinding duration is extended. This suggests that, despite the sieve's large nominal size, the actual particle sizes are smaller, and longer grinding times lead to a more pronounced reduction in average particle diameter.

A valuable observation from the analysis of the graph is that for sieves with larger dimensions, the efficiency of the grinding process is often reduced, as the ground particles tend to be larger compared to the nominal sieve size. This is manifested by a greater difference between the sieve size and the average particle diameter, indicating that the particles are not fully fragmented to meet the specifications. Thus, as the sieve size increases, it becomes more challenging to achieve an average particle diameter close to the nominal sieve size, which can impact the quality and consistency of the final product. The duration of grinding plays a crucial role in determining particle size, as extended grinding allows particles to undergo additional cycles of fragmentation. For sieves with larger dimensions, where particles may initially have a diameter close to the nominal sieve size, extending the grinding time helps achieve a finer particle size. This adjustment in grinding time allows for better control over particle dimensions, thereby optimizing the grinding process.

According to theory, the specific surface area is inversely proportional to the particle diameter, a relationship that is also demonstrated by our results. The average specific surface area reflects the total surface area available per unit mass of the particles, and generally, a higher specific surface area is desirable because it enhances the product's functionality. Typically, an increase in grinding time leads to a reduction in particle size, which in turn increases the specific surface area, thereby improving the physicochemical properties of the rosehip powder. Figure 5 illustrates the graph showing the variation in the average specific surface area of particles as a function of grinding time for particles passed through sieves of different sizes: 0.2 mm, 0.5 mm, 1 mm, and 4 mm.

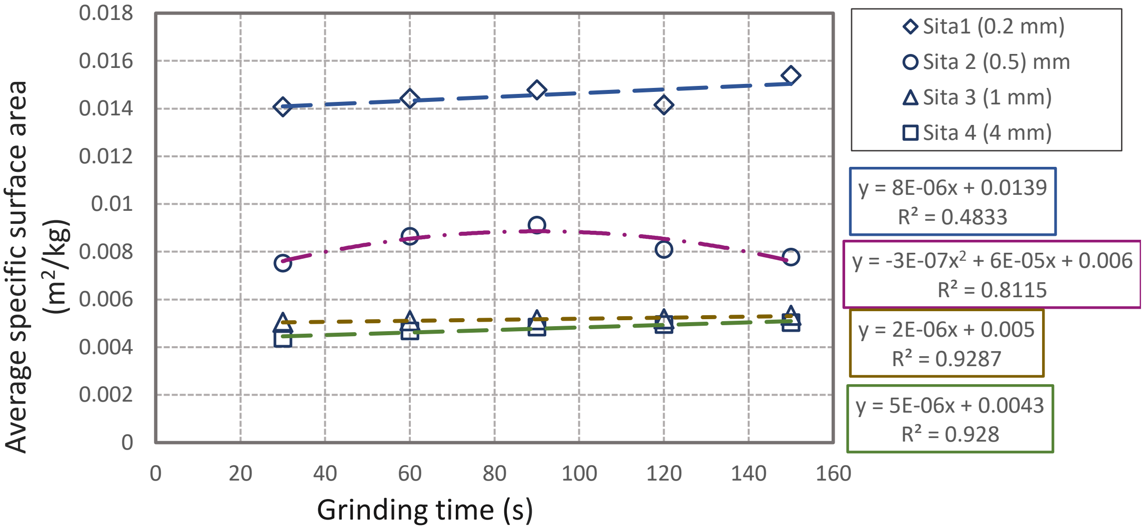

Fig. 5 - Variation of average specific area with grinding time for different sieve sizes

For the 0.2 mm sieve, a clear upward trend in the average specific surface area is observed as the grinding time increases. The positive slope of the equation (8E-06) indicates a consistent rate of increase in specific surface area, meaning that particle size gradually decreases as grinding time is extended. However, the moderate R^2 value suggests that while the overall trend is upward, there is some variability in the measured data, likely due to the complex phenomena of fine particle agglomeration.

The evolution of the curve corresponding to the 0.5 mm sieve exhibits a parabolic behavior, characterized by an initial increase in specific surface area followed by a subsequent decrease, indicating an optimal grinding efficiency around the peak value. This phenomenon can be attributed to particle size reduction reaching a critical threshold, beyond which agglomeration or structural changes may occur, leading to a decrease in exposed surface area. Therefore, the grinding time must be carefully optimized to prevent the adverse effects of over-grinding. The distinct behavior of this sieve highlights a heightened sensitivity to the duration of the grinding process.

Furthermore, regarding the 1 mm sieve the trend line has a slightly positive slope and a high coefficient of determination ($R \approx 0.93$). This suggests a strong correlation between the grinding time and the average specific surface area, with the specific surface area increasing slightly as the grinding time increases. The data are very well explained by this trend line, indicating a clear linear relationship.

Similarly, for the 4 mm sieve, the trend line has a positive slope and a very high coefficient of determination ($R \approx 0.93$). This indicates a strong correlation, with the average specific surface area increasing significantly as the grinding time increases. Much like with the 1 mm sieve, the data are very well explained by this trend line, demonstrating a consistent and predictable increase in specific surface area.

Overall, this graph illustrates how sieve size influences the dynamics between grinding and agglomeration during the milling process. For fine particles (sieve of 0.2 mm and 0.5 mm), the agglomeration phenomenon plays a more significant role, slowing down the decrease in particle size and, consequently, leading to a more pronounced increase in the mean specific surface area. On the other hand, for larger particles (sieve of 1 mm and 4 mm), the grinding process predominates, resulting in a linear and steady increase in the mean specific surface area as grinding time increases. This in-depth analysis of the relationship between grinding time, sieve size, and mean specific surface area provides a valuable overview of the complex dynamics occurring within the milling process. It can be used to optimize process parameters and achieve the desired particle size distribution based on specific application requirements.

In Figure 6, the graph illustrates the relationship between sieve mesh size and the evolution of average specific surface area as a function of grinding time. The following general trends can be observed: the average specific surface area decreases as the sieve size increases, from sieve 1 (0.2 mm) to sieve 4 (4 mm), and for each sieve, there are variations in the specific surface area depending on the grinding time. Additionally, the average specific surface area of the ground material decreases linearly with the increase in sieve aperture size.

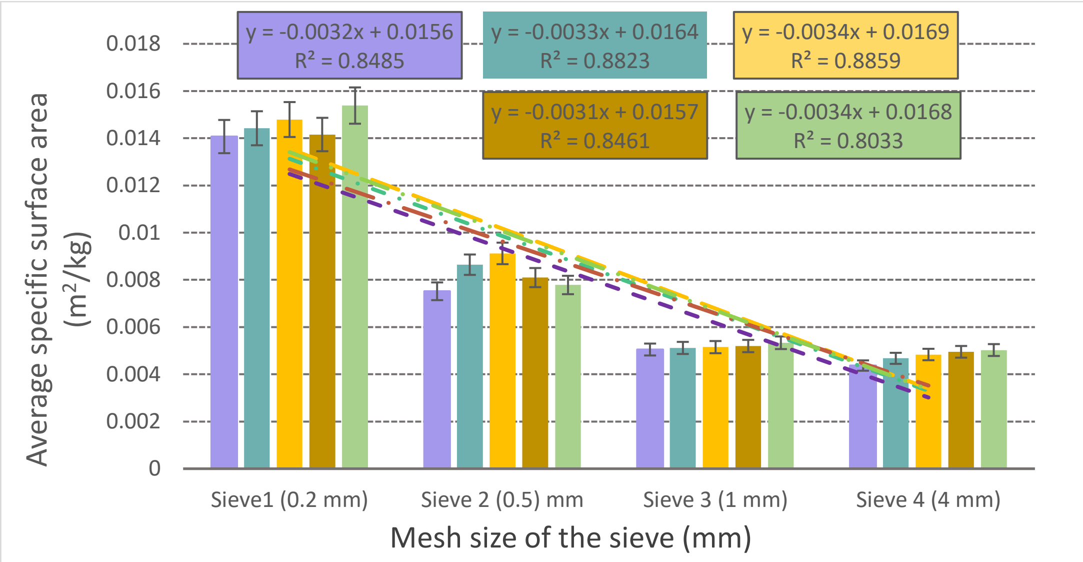

Fig. 6 - The relationship between sieve mesh size and average specific area evolution based on grinding time

Sieve 1 presents the highest average specific surface area, ranging from approximately 0.014 to 0.0154 m²/kg. There is a general trend of increasing specific surface area with longer grinding times, with a slight decrease observed at 120 seconds. The maximum value of the specific surface area is reached at 150 seconds of grinding.

Also, sieve 2 shows a significantly lower average specific surface area compared to Sieve 1, ranging from approximately 0.0075 to 0.0091m²/kg. There is an increase in the specific surface area up to 90 seconds, followed by a decrease for longer grinding times.

Increasing the grinding time has a positive but limited effect on the specific surface area for this Sieve 3 size. Even after 150 seconds of grinding, the specific surface area remains significantly lower than that obtained with finer sieves (Sieve 1 and Sieve 2), but slightly higher than for Sieve 4. Extending the grinding time from 30 to 150 seconds can be beneficial, but the gains are less significant compared to switching to a finer sieve. These larger particles may be preferred in certain applications for their physical properties.

Although Sieve 4 produces particles with the smallest specific surface area, the relative increase with grinding time is more pronounced compared to the finer sieves. This suggests that for larger particles, grinding time has a proportionally greater impact on the specific surface area. However, increasing the grinding time involves higher energy consumption. It is important to evaluate whether the benefit of increased specific surface area justifies the additional energy cost. Longer grinding times may also lead to increased equipment wear, which should be considered in process planning. A potential avenue for further research would be to investigate whether the observed trend of increasing specific surface area continues beyond 150 seconds or if it reaches a plateau. The behavior of Sieve 4 demonstrates that, even for larger particles, there are significant opportunities to optimize the specific surface area by adjusting the grinding time.

CONCLUSIONS

This study highlights the critical role of both grinding time and sieve size in determining the average particle diameter, specific surface area, and overall particle size distribution of rosehip powder. The 0.2 mm sieve, combined with a grinding time of 150 seconds, was found to be the most effective in producing the smallest average particle diameter and the highest specific surface area, making it ideal for applications requiring maximum reactivity or solubility. However, this approach also results in higher energy demands and potential equipment wear, underscoring the need for a balanced approach. The 0.5 mm sieve at 90 seconds of grinding offers a more energy-efficient alternative, achieving a moderately small average particle diameter and a high specific surface area while minimizing the negative impacts of prolonged grinding.

This makes it a suitable choice for applications where a balance between fine particle size, energy efficiency, and operational practicality is required. Conversely, larger sieves (1 mm and 4 mm) demonstrated that while extended grinding can decrease the average particle diameter and increase the specific surface area, these gains are incremental and come with significantly higher energy consumption and wear on the equipment. This study suggests that for most applications, a mid-range sieve size like 0.5 mm, paired with a moderate grinding duration, provides an optimal balance between reducing particle diameter, enhancing specific surface area, and maintaining energy efficiency and equipment durability. Further research is recommended to explore the potential benefits of extending grinding time beyond 150 seconds, particularly for coarser sieves, to determine if further reductions in average particle diameter and increases in specific surface area are possible or if a plateau is reached.

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