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Enhancing Homogeneity and Particle Size Reduction in Coffee–Creamer Mixtures Using Fluidized Bed Mixer

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Abstract

This study investigates the application of a fluidized bed mixer to improve the homogeneity, particle size distribution, and moisture reduction of coffee and creamer powder mixtures. The research focuses on three types of coffee particles—Type A (145 µm), Type B (100 µm), and Type C (50 µm)—which were mixed with creamer in a weight ratio of 1:0.7. The mixing process was conducted using a prototype fluidized bed mixer with a capacity of 1,000 grams and a blower speed range of 2,800–3,000 rpm. After 10 minutes of mixing, significant reductions in particle size were observed: Type A decreased by 20–30%, Type B by 10–15%, and Type C by 5–10%, with creamer particles also experiencing a 15% reduction. Moisture content dropped from 10.63% to 8.5%, demonstrating the system's dual function of mixing and drying. Microscopic analysis revealed a uniform particle distribution with minimal agglomeration or segregation, confirming the effectiveness of the fluidized bed mixer in achieving a homogeneous blend. These findings underscore the potential of fluidized bed technology in improving the quality, stability, and handling properties of powder-based products. The results have important implications for instant beverage production, food formulation, and broader powder processing industries, where consistent product performance is essential.

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1. Introduction

Coffee is a plantation crop with significant economic value and a long cultivation history, particularly in Indonesia, where production has shown a steady increase over time. According to the Central Statistics Agency, Indonesia's coffee production reached approximately 756.05 thousand tons in 2018 and grew to 758.72 thousand tons by 2023 [1]. Coffee is known for its complex and distinctive physical and chemical properties. Physically, it exhibits variations in particle size, weight, extraction time, processing temperature, texture, taste, and aroma [2].

One of the critical challenges in coffee processing, especially in food and pharmaceutical industries, lies in powder mixing. Achieving uniform mixtures of heterogeneous powders such as coffee and creamer is difficult due to differences in particle size, shape, and moisture content [3]. In traditional mixing processes, segregation often occurs—finer particles tend to concentrate in specific areas, while coarser particles form clusters. This non-uniform distribution compromises product quality, which is particularly problematic for applications requiring consistent proportions, such as instant beverage formulations [4].

Furthermore, moisture content in powders significantly affects both product quality and processing efficiency. During grinding, coffee beans are transformed into irregular, non-spherical particles, with a typical sphericity of approximately 0.75 µm [5]. Coffee grinders can break a single bean into 500–800 particles, and in the case of fine grinding, up to 30,000 particles [6]. Sphericity reflects the roundness of a particle; high sphericity indicates uniform grain size, which can affect the behavior of particles during mixing.

The mechanical properties of coffee beans are influenced by moisture content and roasting level (Arabica or Robusta) [7]. Due to the cellular structure of the beans, coffee grinding results in a polydispersed particle size distribution [8]. These factors, along with extraction kinetics and hydrodynamic behavior during mixing, must be considered when designing an efficient mixing process.

Robusta beans, for example, have a geometric volume of 13.80 cm^3, an average surface area of 16.04 cm^2, a volume of 0.021 cm^3, a specific gravity of 218.94, pH of 6.79, total acidity of 0.15%, and moisture content of 10.63% [9]. Reducing particle size increases the surface area in contact with the solvent, thereby enhancing extraction efficiency.

Despite the importance of these factors, research on the hydrodynamics of coffee powder during mixing remains limited. Parameters such as particle size distribution, bulk density, and porosity—especially in the context of solid mixing using fluidized bed technology—have not been adequately explored. Solid mixing involves the combination of two or more solid materials to achieve a uniform distribution, while maintaining the inherent properties of each component [10]. This process is commonly applied in industrial, agricultural, and pharmaceutical settings [11]. In heterogeneous mixtures, the individual particles remain distinguishable, such as in a mixture of coffee and creamer, where visual color differences highlight incomplete mixing (Figure 1).

Figure 1. Mixture of coffee and creamer

Mixing in powder systems is governed by diffusion caused by molecular motion. Physical properties such as density and viscosity of the particles influence mixing behavior. Segregation occurs when particles differ in size, shape, or specific gravity, resulting in uneven spatial distribution. This phenomenon is evident in fluidized bed systems (Figure 2), where initial separation by particle diameter can be observed before full homogenization is achieved after extended mixing.

Figure 2. Mixture of coffee and creamer in a fluidized bed mixer; (a) Separation of groups of particles based on similar diameters in the mixture. (b) The mixture was homogenized after 10 minutes of mixing

To ensure consistent product quality, it is essential to minimize segregation and maximize uniformity, even though perfect homogeneity in solid mixing is inherently difficult to achieve compared to liquid systems.

This study addresses the specific challenges of achieving homogeneity in mixtures of coffee powder and creamer, with a focus on reducing particle size and moisture content. The existing research gap lies in the limited understanding of how fluidized bed mixing can enhance the uniformity of mixtures with diverse particle characteristics while simultaneously reducing moisture. Although fluidized bed technology has shown promise in powder mixing, there is insufficient data regarding its performance in mixing coffee and creamer, particularly under varying particle size conditions.

The primary objective of this research is to evaluate the effectiveness of fluidized bed mixing in reducing the particle size and moisture content of coffee–creamer mixtures and to assess the homogeneity of the final blend. By analyzing the behavior of coffee particles of varying sizes (Type A: 145 µm, Type B: 100 µm, and Type C: 50 µm), this study aims to provide insights into the potential of fluidized bed technology for producing consistent, high-quality powder blends suitable for food and beverage applications.

2. Methods

2.1. Materials

This study used Robusta ground coffee sourced from the Papua region of Indonesia, selected for its strong flavor profile and common use in ground coffee products. The purpose of the experiment was to assess the performance of a custom-designed fluidized bed mixing machine, specifically evaluating its ability to achieve uniform mixing of solid particles (coffee and creamer) and to reduce particle size and moisture content.

Robusta coffee was ground and then sieved using standard mesh sizes—mesh 20, 100, and 200—to obtain relatively homogeneous particle sizes. The particle size groups were classified as:

- Type A: 145 µm (passes mesh 20, retained on mesh 100)
- Type B: 100 µm (passes mesh 100, retained on mesh 200)
- Type C: 50 µm (passes mesh 200)

A coffee-to-creamer mass ratio of 100:70 g was used. Individual samples of each particle type were weighed: 27 g for Type A, 32 g for Type B, 38 g for Type C, and 40 g for creamer.

To assess particle density and quantity, the following theoretical relationships were applied:

$$\rho = {}^{m}/_{v} \tag{1}$$

$$v^1 = \psi . \pi . \left({}^{D}/_{2}\right)^3 \tag{2}$$

$$n = v^1/v \tag{3}$$

where;
ρ = coffee particle density (kg/m^3)
m = coffee mass (kg)
v = coffee volume (m^3)
v^1 = volume of a single particle
n = number of coffee granules
ψ = sphericity

The type of coffee used in this research was Robusta ground coffee, specifically sourced from the Papua region of Indonesia, known for its strong flavor and bold characteristics. Robusta was selected due to its widespread use in ground coffee products and its suitability for dry blending applications.

To achieve a uniform particle size, the coffee grounds were passed through a series of mesh sieves—mesh 20, mesh 100, and mesh 200—corresponding to particle sizes of approximately 145 µm, 100 µm, and 50 µm, respectively. This sieving process ensured that the coffee particles were categorized into well-defined size groups prior to mixing, thus enabling a controlled and consistent evaluation of the mixing process.

To evaluate the performance of the solid-solid mixing process, the resulting mixture was examined under a microscope at 200× magnification. The uniformity of the mixture was assessed by visually analyzing the distribution of particles. A mixture was considered homogeneous when the coffee and creamer particles were evenly dispersed throughout the sample, with no significant clustering or segregation.

In addition, sphericity—a measure of how closely a particle's shape resembles a perfect sphere—was used to further describe the physical properties of the coffee granules. Sphericity (ψ) is defined as:

$$\psi = {}^{(Perimeter)^2}\Big/_{Surface\ Area} \tag{4}$$

Mesh 20 Mesh 100 Mesh 200

Figure 3. Mesh sieves used for particle size classification (Mesh 20, 100, and 200)

A sphericity value of 1.0 indicates a perfect sphere, while lower values suggest increasingly irregular shapes. In this study, coffee particles exhibited an average sphericity of approximately 0.75, indicating a relatively rounded form with slight irregularities. Sphericity is a dimensionless value, derived from geometric ratios, and is useful in predicting flow behavior during mixing.

The experiment began by weighing and preparing the materials—ground coffee and creamer—in a mass ratio of 10:7 (g). The coffee grounds were first sieved using mesh sizes 20, 100, and 200, as illustrated in Figure 3, to separate the coffee into distinct particle size categories before the mixing process.

The coffee powder was first filtered using mesh sieves to classify particles based on size and obtain consistent particle fineness and average dimensions. This step was critical for ensuring uniform mixing behavior. Following the sieving process, the volume of the sample containers was measured, as shown in Figure 4.

Figure 4. Measurement of container volume used for weighing coffee powder samples

Coffee A (27 g) Coffee B (32 g) Coffee C (38 g) Creamer (40 g)

Figure 5. Mass measurements of coffee samples (A, B, C) and creamer

Three categories of coffee particle sizes—Type A, B, and C—were prepared with corresponding weights, along with creamer, as follows:

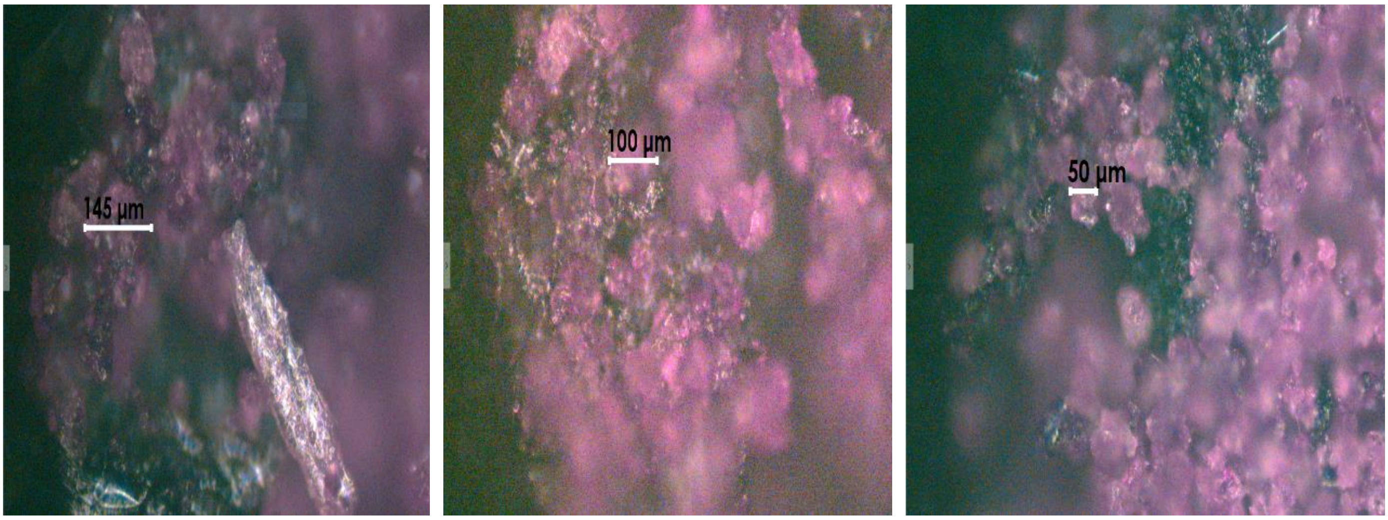
- Coffee A: 27 g (largest particles)
- Coffee B: 32 g
- Coffee C: 38 g (smallest particles)
- Creamer: 40 g

To evaluate the bulk density of each coffee type, the mass and volume of the samples were recorded, and density was calculated using equation (1). The results are presented in Table 1, which shows a trend of increasing density with decreasing particle size. This suggests improved packing efficiency for smaller coffee particles.

Table 1. Calculation of coffee density

Type	Volume v (m^3)	Mass m (kg)	Density ρ (kg/m^3)
A	0,5	0,027	0,054
B	0,5	0,032	0,064
C	0,5	0,038	0,075

To further analyze particle morphology and size, samples were observed using a Meiji MT7100 microscope at 200× magnification, as shown in Figure 6.



Coffee A Coffee B Coffee C

Figure 6. Microscopic images of coffee samples A, B, and C at 200× magnification

The average diameters of the coffee particles were measured as follows:

- Type A: 145 µm
- Type B: 100 µm
- Type C: 50 µm

These results were consistent with the sieving process. Specifically:

- All samples passed through mesh 20
- Types B and C passed through mesh 100
- Only Type C passed through mesh 200

This size classification confirmed the effectiveness of the filtration step in achieving well-defined particle categories for further mixing evaluation.

2.2. Experimental setup

A fluidized bed mixer was used in this study to evaluate its effectiveness in mixing coffee and creamer powders. The mixer has a capacity of 1,000 grams and is designed with an acrylic mixing chamber measuring 14 cm in diameter and 50 cm in height. It is equipped with a 500-watt variable-speed blower, operating in the range of 2,800 to 3,000 rpm, to provide the controlled airflow necessary for fluidization (Figure 7).

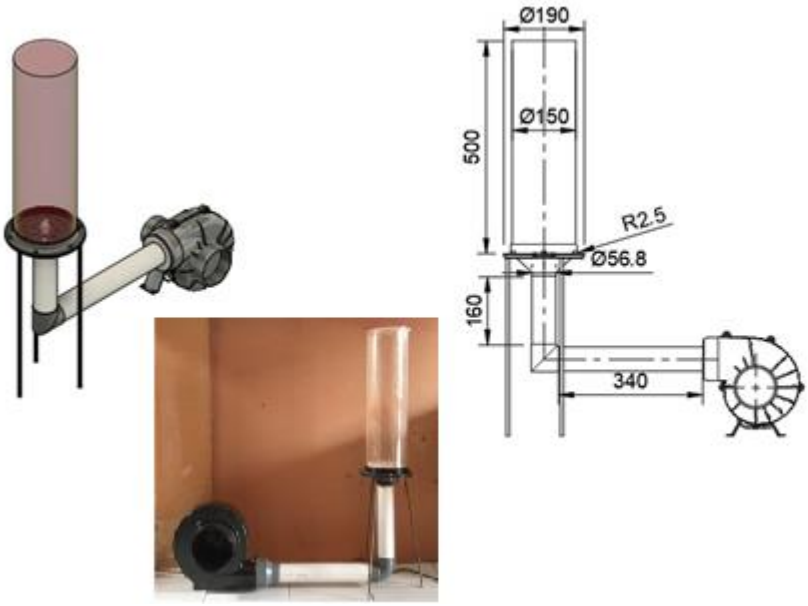


Figure 7. Fluidized bed mixer used in the experiment

The mixing chamber includes a perforated distributor plate positioned at the base. This plate evenly distributes the air pressure, supporting and suspending the coffee particles during the mixing process. This setup enables particles to behave like a fluid, a phenomenon fundamental to fluidization. The blower delivers pressurized air that overcomes the static pressure of the bed, causing the powder to rise and circulate in a suspended state.

Fluidized bed technology, commonly used in mixing and drying applications, creates a fluid-like motion of fine solid particles by passing air or gas upward through the powder bed [12], [13]. Previous studies have applied various mixers—rotary, vertical, and fluidized stirrers—to optimize solid mixing [14], [15].

The performance of the solid–solid mixing process was evaluated by assessing the homogeneity of the final mixture using a microscope at 200× magnification. A mixture was considered uniform when the particles were well-distributed with no visible segregation or clustering (Figure 9).

To begin the process, the fluidized bed mixer was cleaned and assembled. A coffee-to-creamer mass ratio of 1:0.7 was used, and the materials were introduced into the mixing chamber. The chamber lid was sealed to prevent leakage. The blower started at a low speed, and air began flowing through the porous distributor plate at the bottom of the chamber. Initially, the airflow was insufficient to mobilize the particles, maintaining a fixed bed. As the blower speed increased, the air pressure became sufficient to overcome the weight of the coffee and creamer particles, resulting in laminar movement. Upon reaching a stable fluidization state, the particles were observed to float and mix uniformly, as shown in Figure 8.

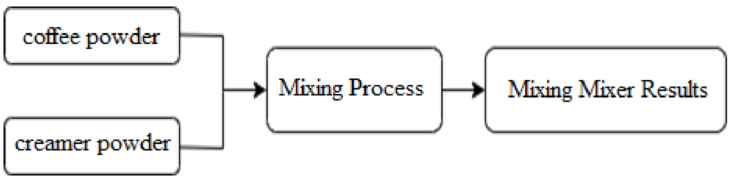


Figure 8. Coffee stirrer working concept

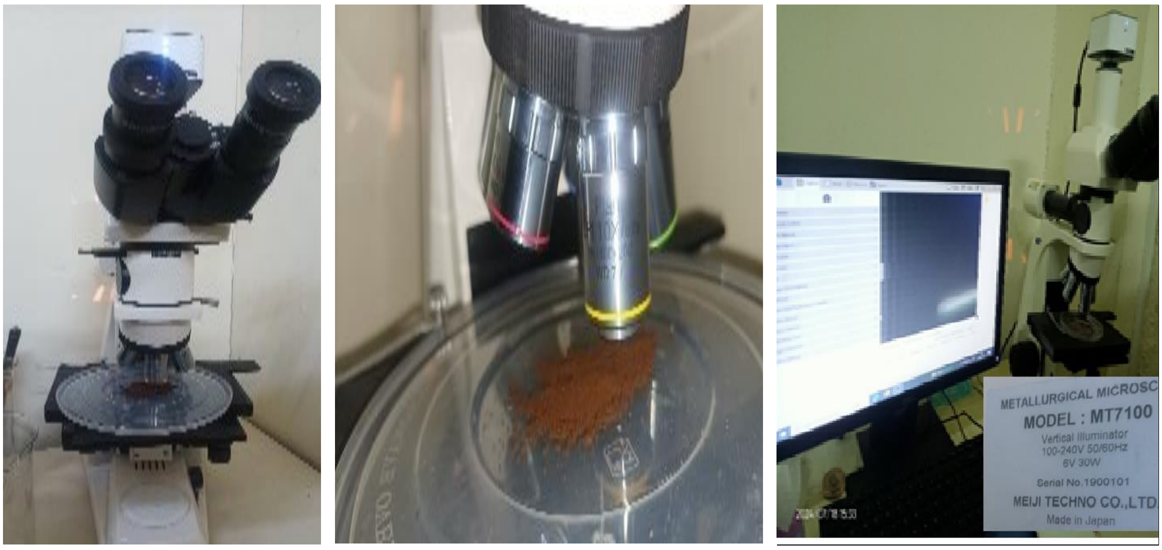


Figure 9. Microscopic image of coffee-creamer mixture at 200× magnification

After a predetermined mixing duration, the fluidized bed mixer was turned off and the mixture was collected for observation. The uniformity of the coffee–creamer blend was visually assessed using a Meiji MT7100 microscope at 200× magnification (Figure 9). Figure 10 presents the post-mixing samples of Coffee A, B, and C, which visually demonstrate the distribution uniformity achieved with varying particle sizes.

Coffee A Coffee B Coffee C

Figure 10. Mixed samples of Coffee A, B, and C with creamer

Proper fluidization depends on maintaining a consistent airflow rate and monitoring moisture and particle behavior to avoid structural damage due to drying [16], [17]. Thus, the fluidized bed setup in this experiment served not only as a mixing apparatus but also allowed preliminary observations on the impact of airflow on moisture control. The default stirring speed setting must be made at a constant rotation [18].

3. Results and Discussion

The calculation results of the test data are summarized in Table 2, which presents the physical characteristics of the coffee particles, including volume, mass, diameter, sphericity, estimated particle volume, and the calculated number of granules.

Table 2. Coffee granules calculation data

Type	Volume v (m^3)	Mass m (kg)	Diammeter D (μm)	Diammeter D (μm) = meter	Sphericity ψ (m) ~ 0,75 μm	Volume of Coffee Particles v^1	Number of Coffee Granules n
A	0,5	0,027	145	0,000145	0,00000075	8,98256E-19	5,5663E+17
B	0,5	0,032	100	0,0001	0,00000075	2,94643E-19	1,697E+18
C	0,5	0,038	50	0,00005	0,00000075	3,68304E-20	1,3576E+19

As shown in Table 2, the number of coffee granules varies significantly based on particle size. Type A coffee, with the largest average diameter (145 μm), contains fewer particles, while Type C, with the smallest diameter (50 μm), has a significantly higher particle count. This difference is due to the inverse relationship between particle diameter and the number of particles per unit volume, assuming equal total volume across types.

After mixing coffee and creamer in the fluidized bed mixer, samples were collected and analyzed to evaluate the homogeneity of the mixture. Ideally, a well-mixed system is achieved when each particle of one component (e.g., coffee) is uniformly surrounded by particles of the other (e.g., creamer). This ensures maximum contact and distribution, resulting in a homogeneous mixture. Figure 11 presents the visual outcomes of mixing coffee and creamer for each particle size group.

The fluidization process induces turbulent flow due to the rapid and irregular motion of air and powder particles near the base of the chamber. This turbulence enhances the mixing process through three key mechanisms:

1. Convection (bulk transport): Large volumes of material are displaced and redistributed from one region of the mixing chamber to another.
2. Shear: Layers of material move relative to one another, breaking up clusters and promoting interparticle contact.
3. Diffusion: As particles are lifted and suspended by the airflow, the powder bed expands, increasing void spaces and enabling fine particles (such as creamer) to move into gaps between larger coffee particles.

The formation of air voids and bubbles during fluidization allows powder particles to redistribute in a dynamic and random fashion. This individual particle motion is essential for achieving a "random-mix" condition where the probability of encountering different particle types is uniformly distributed throughout the mixture. The differences in particle count and diameter, combined with the turbulent flow and fluid-like behavior in the fluidized bed, facilitated effective mixing. Finer particles (such as Type C coffee) had more particle-to-particle interaction due to higher surface area, which likely contributed to a more uniform and cohesive mixture with the creamer.

Coffee A Coffee B Coffee C

Figure 11. Mixing results of coffee and creamer for Types A, B, and C

Finer particle sizes generally result in higher packing density and lower moisture content. Due to their increased surface area and reduced void space, smaller particles tend to bond more closely, forming a more compact and cohesive structure. This behavior enhances the effectiveness of the mixing process, as fine particles are more evenly distributed and less prone to segregation.

In this study, ideal mixing conditions refer to a state where coffee and creamer particles are uniformly distributed, with no visible separation or clustering. While there is no formal quantitative standard for "perfect mixing" in this context, homogeneity is typically assessed through visual inspection or microscopic analysis of representative samples. A mixture is considered homogeneous when the distribution of particles appears even throughout the sample, without concentration gradients or phase separation.

Achieving such homogeneity requires that particles of different types (e.g., coffee and creamer) are in frequent contact with each other. This is facilitated by three primary mixing mechanisms:

1. Diffusion – random movement of individual particles at the microscopic level.
2. Convection – bulk movement or displacement of groups of particles across the mixing zone.
3. Shear – relative motion between adjacent layers of powder, breaking up agglomerates and enhancing intermixing.

These mechanisms, especially when combined in a fluidized bed system, work together to promote uniform particle distribution. By maximizing contact between different particles, the process ensures that the final mixture is consistent in composition and quality.

Microscopic observations of the coffee particles after mixing are shown in Figure 12, which displays the grain morphology for Types A, B, and C:

- Type A: initial grain diameter of 145 μm
- Type B: initial grain diameter of 100 μm
- Type C: initial grain diameter of 50 μm

From the microscope images, it was observed that mixtures with higher moisture content exhibited darker visual textures, indicating water retention within the powder structure. Additionally, due to their finer size and sugar content, creamer particles tend to occupy the voids between coffee granules, especially in blends with finer coffee particles like Type C. This not only improves the binding between particles but also enhances the cohesion of the mixture. As a result, in Type C mixtures, creamer appears more evenly distributed, contributing to a more uniform texture.

The mixing behavior is significantly influenced by bulk transport, which corresponds to the convective movement of powder masses from one region of the mixer to another. However, effective mixing can be hindered by particle segregation, particularly when differences in particle density are present, even if the sizes are similar.

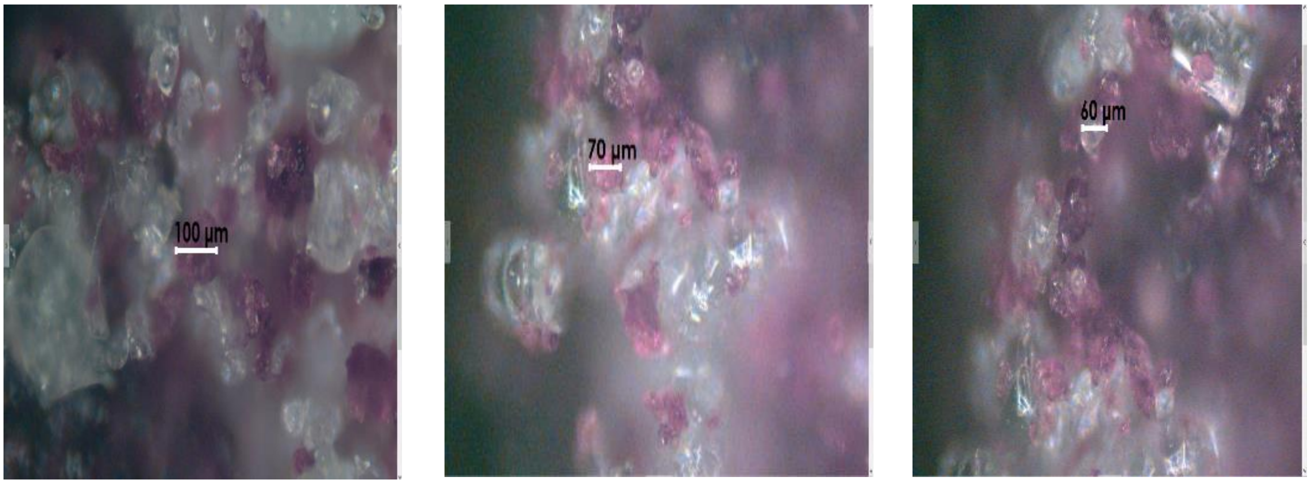
One major challenge in powder mixing is the cohesion or adhesion between particles, especially when dealing with fine or compositionally different materials. Highly cohesive particles tend to form agglomerates, making uniform mixing more difficult. In such cases, high-flow-rate milling or extended mixing may be required to alter grain shapes and break up clusters.

As particles move randomly during fluidization, they continuously change their positions relative to one another. This random exchange of positions contributes to the reduction of segregation intensity and promotes homogeneity. According to Weinekötter et al. (2000), a mixture is considered ideal when the particle concentration at any randomly selected point is equivalent to the average concentration throughout the mixture [19].

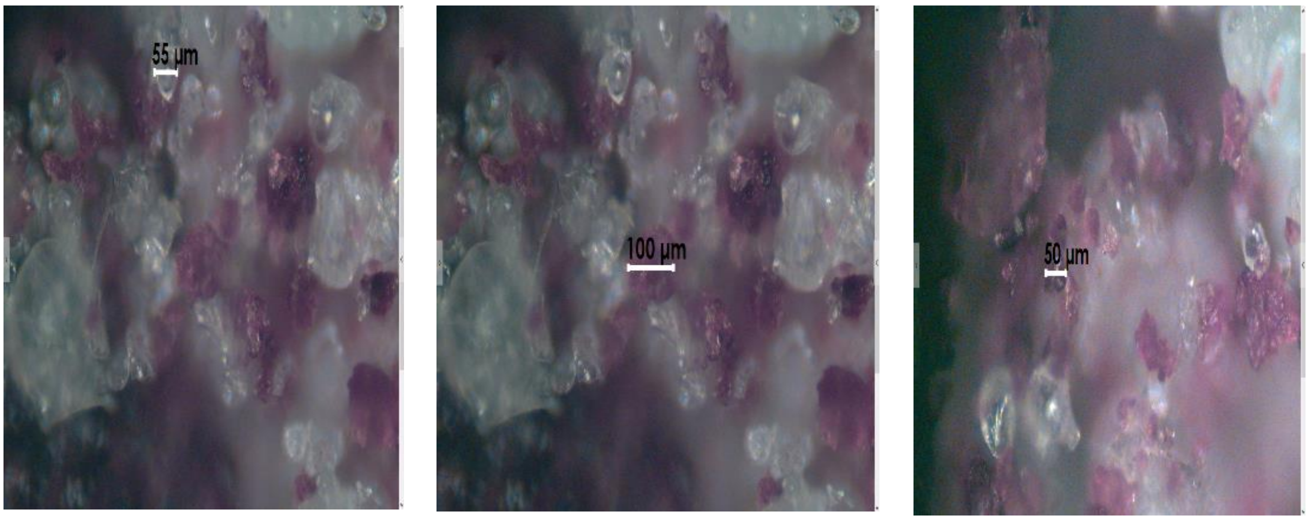
Furthermore, longer mixing durations have been shown to improve homogeneity [20]. Extended stirring times also contribute to particle size reduction and an increase in packing density. Simultaneously, moisture content tends to decrease with longer mixing, as noted by Hasibuan et al. (2019), which further improves the stability and flowability of the final powder blend [21].

The effectiveness of the fluidized bed mixer in achieving homogeneity in the coffee and creamer mixture was evaluated using both qualitative and quantitative methods. Qualitative analysis was conducted through microscopic observation using a Meiji MT7100 microscope at 200× magnification, which allowed visual assessment of particle distribution and the uniformity of the blended materials. Homogeneity was judged based on the even dispersion of particles and the minimization of segregation between components of differing particle sizes.

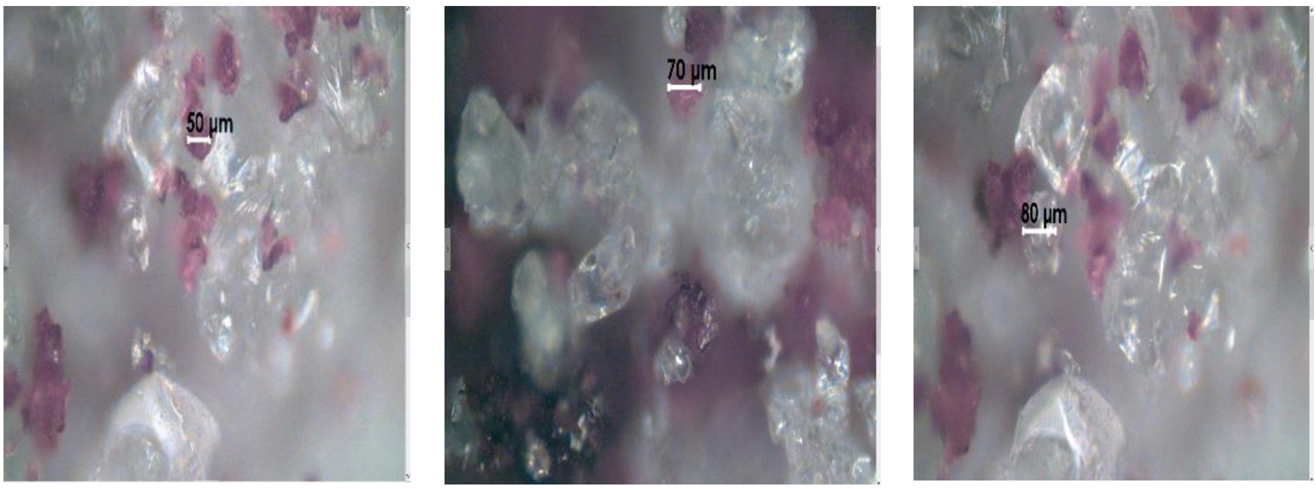
Quantitatively, the particle size distribution of coffee granules was measured before and after mixing. The initial particle sizes were 145 μm (Type A), 100 μm (Type B), and 50 μm (Type C). After mixing, the average particle sizes were reduced to approximately 100 μm for Type A (a reduction of 20–30%), 90 μm for Type B (10–15% reduction), and 45 μm for Type C (5–10% reduction). These reductions confirm that the fluidized bed mixer not only facilitates blending but also contributes to particle size reduction, which is beneficial for improving extraction efficiency in coffee preparation.



(a) Type A coffee, the initial coffee grain diameter is 145 micrometers



(b) Type B coffee, the initial coffee grain diameter is 100 micrometers.



(c) Type C coffee, the initial coffee grain diameter is 50 micrometers.

Figure 12. Microscopic view of coffee particles after mixing (200× magnification)

Homogeneity was further evaluated by calculating the Relative Standard Deviation (RSD) of particle sizes across different sampling points. A well-mixed system was defined as one with an RSD not exceeding 10%, indicating minimal variation in particle distribution. The results showed that the final mixture met this criterion, confirming a high degree of mixing uniformity.

Another important parameter assessed was moisture content. The initial water content of the coffee mixture was 10.63%. After 10 minutes of fluidized bed mixing, the moisture content decreased to 8.5%. This reduction demonstrates that the mixer not only promotes physical blending but also provides a drying effect, which is advantageous for preventing clumping and improving powder stability during storage and handling. These findings suggest that the fluidized bed mixer is highly effective for producing homogeneous, fine-particle mixtures with reduced moisture content—properties that are critical for maintaining consistent quality, especially in the food and beverage industry. Applications such as instant coffee production, powdered drink formulations, and pharmaceutical blends can benefit significantly from this mixing technology.

However, several limitations of the current prototype were identified. The 1,000-gram capacity is adequate for laboratory-scale studies but may not meet the demands of large-scale or industrial production. Furthermore, the current blower and airflow distribution system may require optimization to ensure consistent mixing at higher volumes. Enhancements such as variable airflow control and improved air distribution designs could increase efficiency, particularly when handling powders with diverse particle sizes and densities. Additionally, the mixing process must be carefully monitored for temperature and humidity to avoid excessive drying, which could negatively impact heat-sensitive materials like coffee. Future research should explore process optimization strategies, including real-time control of environmental conditions, to achieve a better balance between mixing performance and moisture control.

4. Conclusions

This study has demonstrated the effectiveness of fluidized bed mixing technology in improving the homogeneity, reducing particle size, and lowering moisture content in coffee and creamer mixtures. The results showed that particle size reductions were most pronounced in Type A coffee (20–30%), followed by Type B (10–15%) and Type C (5–10%). Furthermore, the moisture content was reduced from 10.63% to 8.5% after 10 minutes of mixing, indicating the dual functionality of the fluidized bed system in both blending and drying operations. These improvements are significant for enhancing coffee extraction efficiency and for improving the texture, solubility, and shelf stability of powdered beverages. The practical implications of these findings are particularly relevant to the food and beverage industry, where consistent product quality and efficient formulation processes are critical. The ability of the fluidized bed mixer to simultaneously reduce particle size and moisture content contributes to better integration of ingredients, leading to improved taste, reconstitution performance, and product uniformity. In the context of coffee processing, these results offer promising avenues for improving instant coffee and other powdered drink formulations. However, the current study also presents several limitations. The fluidized bed mixer used had a limited capacity (1,000 grams), which, while suitable for laboratory trials, may not fully represent conditions in large-scale industrial applications. In addition, while improvements in particle size and moisture content were achieved, the long-term impact on coffee's sensory qualities—such as flavor and aroma—remains to be evaluated. The design of the air distribution system may also influence mixing efficiency and could require optimization when dealing with larger batches or mixtures with broad particle size distributions.

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