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Impact of local cassava cultivars and particle size on dimensional, shape, and color properties of cassava flour

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Abstract It was found that dimensional properties consisted of particle diameter, total particle area, and number of particles were significantly influenced by casava cultivar, particle size and the interaction of these two factors. For the shape properties, sphericity was influenced by cassava cultivar; roundness was influenced by particle size; and surface roughness was influenced by both cassava cultivar, particle size, and the interaction of these two factors. For color properties, whiteness index was affected by cassava cultivar, particle size, and the interaction of these two factors; chroma was affected by particle size; and hue angle was affected by cassava cultivar and the interaction of cassava cultivar and particle size. It could also be concluded that produced cassava flour was finer and whiter than the commonly encountered cassava flour, with the sphericity included into spherical and high spherical particles, and roundness of the particle flour classified as rounded and well-rounded. There was a tendency to decrease in particle size which was accompanied by decreasing surface roughness, and this smaller particle size produced a higher whiteness index. Finally, the choice of cassava cultivar and particle size was very important in obtaining flour with the desired properties.

Keywords: Cassava, Color properties, Cultivar, Dimensional properties, Particle size, Shape properties

Introduction

Cassava flour is processed cassava tubers that gained popularity as a substitute for wheat flour with unique advantages for bakers and customers (Udoro *et al*., 2021a; Marchetti *et al*., 2024). Since cassava grows well in tropical and subtropical climates such as Indonesia, producing cassava flour locally to reduce imported wheat is a feasible strategy for food security and food self-reliance. Hasmadi *et al*. (2020a) stated that composite flour to produce baked goodswill help reduce dependence on imported wheat. However, cassava flour does not replicate every baking attribute of wheat flour (Lu, 2020; Noort *et al*.,

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2022; Renzetti *et al*., 2023), primarily due to its low protein and high starch, which affect the quality and texture of baked foods.

Biscuits are a shelf-stable and adaptable food item made of wheat flour but not preferable by consumers with celiac disease or gluten intolerance (Kohli *et al*., 2023; Marta *et al.,* 2024a). This can be addressed by substituting wheat flour with cassava flour, which is naturally gluten-free. The physicochemical characteristics, specifically its high starch content and restricted gluten-like activity, can present difficulties when producing biscuits (Oyeyinka *et al*., 2019). High starch and protein content in cassava is attributed to cassava cultivar (Rahmawati *et al*., 2024). The choice of cassava cultivar can substantially affect the microstructure of the resulting biscuits. The variation in question stems from inherent disparities in starch characteristics among different cultivars (Ratnawati and Desnilasari, 2020). The size of starch granules, the quantity of amylose, and the structure of amylopectin are contingent upon the variety of cassava (Eke *et al*., 2009).

Wheat flour biscuits are a popular gluten-loaded snack but unsuitable for people with celiac disease or gluten intolerance (Kohli *et al*., 2023; Marta *et al*., 2024b). The alternative to wheat flour is mocaf (modified cassava flour) which is naturally gluten-free and potential to improve its properties (Eduardo *et al*., 2013; Cazzaniga *et al*., 2021). Fermented cassava flour can increase batter viscosity and dough density (Sigüenza-Andrés *et al*., 2021), improve water absorption, and decrease the extensibility and specific volume of baked products due to the absence of gluten structure (Cazzaniga *et al.,* 2021). However, dough made of modified cassava flour has a low-crumb texture (Monthe *et al*., 2018). The microstructure of biscuits is substantially affected by inherent starch characteristics of particular cassava cultivars (Ratnawati and Desnilasari, 2020), such as the size of starch granules, the amount of amylose, and the structure of amylopectin of different cassava cultivars (Eke *et al*., 2009; Rahmawati *et al*., 2024). In addition, physicochemical characteristics that may include high starch content and limited gluten-like activity can pose difficulties when producing biscuits (Oyeyinka *et al*., 2019). Other characteristics of baked confectionery products that require deeper investigation include softness and unstable strength (Udoro *et al*., 2021).

The texture and quality of cassava products made of mocaf powder are highly dependent on the flour particle size (Chisenga *et al*., 2019; Sigüenza *et al*., 2021). The smoother, finer cassava particles results make biscuits denser and harder (Ikechukwu and Oyiza, 2021), while larger particles are typically coarser, making biscuits more crumbly (Engelen *et al*., 2005). The particle size of cassava flour can be controlled by mesh sizing; for example, mesh sizes 100 and 140 represent intermediate particle sizes compared to coarser or finer meshes. This range is optimal for baking application, which requires a balance between particle size and flour properties to obtain the desired texture of the baked biscuit, which is soft with crumbly consistency. As particle size distributions of rice flours affect the microstructure and texture of gluten-free bakery products, researchers have recommended some particle sizes for optimum results of flour-based food, such as 100-140 mesh of dry-milled rice flour for rice crackers (Nammakuna *et al*., 2009) and 120 and 160 mesh rice flour for cakes (Kim and Shin, 2014). This research uses 100 and 140-mesh Tyler sieves for cassava flour to observe its various properties and potential as a raw material in the food industry and understand its practical applications and process improvements. This information can improve the utilization of cassava flour for specific applications and optimize production.

Microscopical analysis of the cassava flour reveals the particle size distribution and its impact on the microstructure of the final products (Gusmao *et al*., 2016), surface roughness, and other parameters. Compared to the conventional analysis, this approach uses a binocular microscope that lends a different perspective to hidden elements in food products and presents them as a concrete and accessible picture of the microscopic world (Auty, 2019; Falkeisen *et al*., 2022). The microscopic structure of cassava flour is relative to the amount of fiber content (Kiper and Uzun, 2017), where high-fiber cassava flour shows larger fiber particles, which result in a rougher texture than wheat flour-based products. The microscopic profile of cassava flour is contingent on the type of cassava cultivars used in the flour making (Chisenga *et al*., 2019). Eriksson *et al.*, (2014) reported that the three cassava varieties used had a significant influence on various parameters of the cassava flour produced, such as whiteness index, color components, starch content, amylose content, pH, and functional properties. Other studies reported similar results on 14 cassava varieties (Wambua, 2017), six varieties (Chisenga, 2019), four varieties (Dewi and Widyastuti, 2021), five varieties (Tappiban *et al*., 2020), and two varieties (Akpoghelie *et al*., 2024). These robust studies have analyzed the conversion of cassava tubers into flour and the desired increased nutrition and reduced antinutrients, but Akpoghelie *et al*. (2024) proposed further research on how this conversion affects the organoleptic and functional properties of the flour. Cassava cultivar selection and the particle size of cassava flour are essential elements in the production of quality cassava flour and derivative products. This research aimed to determine the effect of cassava cultivar and flour particle size on the characteristics of the cassava flour produced in the form of dimension, shape, and color properties.

Materials and methods

Materials

Cassava flour was produced from four cassava cultivars, Kamling, Marjoko, Mertega, and Slenteng, procured directly from farmers in Banyumas, Central Java, Indonesia. Only fresh cassava tubers with intact and undamaged shapes and approximately the same size was processed into cassava flour. Other materials included tap water to wash and soak the cassava tubers and lactic acid bacteria culture for fermentation to modify the flour properties (Afifah *et al.,* 2024).

Production of cassava flour

Cassava tubers were cleaned with tap water to remove soil and impurities, then the skin was peeled manually, and the tubers were cut with a machine into 2-3mm thick chips. The chips were soaked in clean water (1:1 ratio) for 36 h, during which L. casei as functional probiotics (Sellam *et al*., 2024) from lactic acid bacteria (LAB) culture was incorporated with a ratio of 1 ml LAB for 1 kg of chips. LAB was incorporated to allow fermentation that changes the structure of flour granules and produces better characteristics. After soaking, the chips were drained and then oven-dried until the moisture content was 10–12% (w/b) then the dried chips were pulverized to flour. For research purposes, the flour was sieved using mesh 100 and mesh 140 of Tyler sieve in compliance with the required standards in Indonesia stated in (SNI) 7622:2011, which is a minimum of 90% passing the mesh 100 sieve. In this study, flour samples that passed mesh 100 represented the general cassava flour available in the market, while those passing mesh 140 were deliberately made finer to analyze their potentially better properties, particularly when used for subsequent purposes. Figure 1 illustrates the cassava tubers, chips, and cassava flour used in this research.

Dimensional properties

Particle properties of the studied cassava flour were analyzed using ImageJ software (Kouhsari *et al*., 2022; Bagheri, 2015; Azarbad *et al*., 2019), a built-in feature in Java application of image processing with 8-bit, 16-bit, or 32-bit color depth for a variety of purposes. First, the flour was captured, and then the image was sent to ImageJ for the binarization process and further particle analysis. ImageJ characterized the objects by calculating multiple indices and improved particle segmentation by applying grayscale conversion to the image with an 8-bit depth. Otsu's method was utilized in the thresholding technique to distinguish cassava flour particles from the background, and then the thresholding values were adjusted to achieve the most effective particle segmentation. ImageJ used some commands to compute the average particle diameter, total particle area, and number of particles of the flour within the specified picture region. These parameters were measured based on a sizeable number of particles to ensure reliable results.

(a) (b) (c) (d)

Figure 1. Pothos of cassava tuber, chips, flour passing 100 mesh, and flour passing 140 mesh of (a) Kamling (b) Marjoko, (c) Mentega, and (d) Slenteng cultivars

Shape properties

The shape of cassava flour particles was determined using the ImageJ software. The processed image in the previous step was run for the Analyze Particles function in ImageJ to calculate basic particle shape parameters, namely sphericity, roundness, and roughness of flour particles. The shape descriptor of sphericity was determined using derived parameters or specialized plugins.

Sphericity measures how closely a particle resembles a sphere (Barbosa-Canovas *et al*., 2005) and is determined from derived parameters or specialized plugins. Value 1 means a perfect sphere. Roundness is an index to quantify the circularity of a particle, where a perfect circle has a roundness value of one and a non-circular shape has a value of less than one (Maroof *et al*., 2020). Roughness is a measurement of how bumpy or uneven a surface is (Maroof *et al*., 2020). ImageJ took the average height of all the bumps and valleys on a surface compared to a perfectly flat line. The surface roughness was measured in a fractal dimension study with suitable ImageJ plugins or scripts. The results of shape attributes would provide valuable information on the particles' morphology and effects on the properties of cassava flour.

Color properties

The color of cassava flour was measured based on the RGB value of the photos of cassava flour particles, interpreting the red, green, and blue color components of the pixel. The RGB values were transformed into the CIELab color space of L, a*, and b* using conventional colorimetric conversions where L denotes lightness, a* is redness, and b* is yellowness. Based on these CIELab values, we calculated the whiteness index, hue angle, and chroma values to describe the color of the cassava flour. The whiteness index is a numerical metric that quantifies the level of whiteness, where higher values indicate a higher degree of whiteness. The Hue angle indicates the direction of color on the CIELab color space, and chroma measures the color intensity. This series of color analyses enabled the characterization of the chromatic features of the cassava flour.

Data analysis

This study employed a Completely Randomized Design (CRD) with two factors: cassava cultivars (Kamling, Marjoko, Mertega, and Slenteng) and two particle sizes (100 and 140 mesh of Tyler sieve), constituting eight treatment combinations with three replicates. The observed parameters were particle dimensional properties (diameter, surface area, and particle number), particle shape properties (sphericity, roundness, and surface roughness), and color properties (whiteness index, chroma, and hue angle). The mean values were compared using Duncan's Multiple Range Test (DMRT) at a 5% significance level.

Results

Dimensional properties

Statistical analysis revealed that cassava cultivars, mesh size, and the interaction of these two factors significantly affected the particle diameter of cassava flour ($p<0.05$). DMRT analysis showed a similar particle diameter for all types of cassava flour, which was less than 100 µm, except for Kamling 100, which had the largest diameter of 137.52 µm (Table 1). These results demonstrated that local cassava cultivars in this study were feasible for producing fine cassava flour.

The particle surface area of cassava flour in this study varied greatly due to the cultivars, mesh size, and the interaction of both factors ($p<0.05$), ranging from 31,171.87 to 213,334.33 µm^2. Cassava cultivar and particle size are the key factors in obtaining flour with the desired functional properties. The comparison of mean values in DMRT showed that Marjoko cassava flour strained in mesh 140 had the largest flour area (213334.33 μm^2), which was significantly different from other flour (<150000 μm^2) (Table 1). This result agreed with the particle diameter of Marjoko 140, which had the smallest value. Kamling 140 cassava flour, having the largest particle diameter of all cultivars, showed the smallest surface area (31171.87 μm^2).

Statistical analysis indicated that the variety, particle size, and the interaction between cassava cultivar and mesh size significantly influenced the particle number ($p<0.05$). Similar to the surface area, the most particles were observed in Marjoko cassava flour strained with mesh 140, indicating significant differences from other cultivars (Table 1). Therefore, Marjoko cassava was viable for cassava flour with small particle size, large flour area, and many particles.

Table 1. Dimensional, shape, and color properties of the studied cassava flour

Particle Properties	Kamling mesh 100	Kamling mesh 140	Marjoko mesh 100	Marjoko mesh 140	Mertega mesh 100	Mertega mesh 140	Slenteng mesh 100	Slenteng mesh 140
Diameter (μm)	137.52^{c}	36.45^{a}	43.26^{a}	26.39^{a}	74.79^{b}	38.32^{a}	41.07^{a}	42.11^{a}
Area (μm^2)	31171.87^{a}	143135.43^{e}	64739.58^{c}	213334.33^{f}	47828.12^{b}	89552.08^{d}	88270.83^{d}	96333.33^{d}
Number	26.67^{a}	68.00^{e}	47.00^{cb}	98.33^{f}	34.00^{b}	56.00^{d}	51.66^{cd}	53.33^{d}
Sphericity	0.77^{ab}	0.98^{b}	0.50^{ab}	0.78^{ab}	0.35^{a}	0.61^{ab}	0.60^{ab}	0.41^{a}
Roundness	0.21^{a}	0.83^{b}	0.72^{ab}	0.53^{ab}	0.35^{ab}	0.89^{b}	0.52^{ab}	0.77^{ab}
Roughness	1.02^{c}	0.39^{ab}	0.72^{bc}	0.21^{a}	0.30^{a}	0.31^{a}	0.22^{a}	0.29^{a}
Whiteness Index	62.27^{bc}	89.50^{e}	64.28^{c}	80.23^{d}	83.94^{d}	92.76^{e}	56.68^{a}	58.88^{abc}
Chroma	3.84^{b}	1.86^{ab}	2.55^{ab}	2.36^{ab}	2.52^{ab}	1.40^{a}	2.63^{ab}	1.49^{a}
Hue Angle (°)	85.51^{a}	100.36^{bc}	125.72^{e}	128.19^{e}	122.40^{de}	92.91^{ab}	88.97^{ab}	110.60^{bc}

*) values in the same row followed by the same letter are not significant different ($\alpha=0.05$)

Shape properties

The shape properties identified the sphericity, roundness, and roughness of cassava flour's particles (Figure 2 and 3). This study showed that the cassava flour's sphericity was significantly influenced by the cassava cultivar ($p<0.05$) but not significantly affected by the particle size and the interaction of particle size and cassava cultivars. The sphericity value ranged between 0.35 and 1.00, and DMRT results showed that the highest sphericity value was one, as evidenced in some treatments except for Mertega 100 and Slenteng 140, which was below 0.50 (Table 1). Particle's roundness, based on the statistical analysis, was significantly influenced by particle size ($p<0.05$) but not affected by cassava cultivar and cultivar-particle size interaction. The average roundness value was relatively high, above 0.50, except for Kamling 100 and Mertega 100 (Table 1). The surface roughness of cassava flour particles was affected by the cassava cultivar, and the particle size and the interaction of both factors significantly affected the surface ($p<0.05$). The DMRT results analysis indicated a significant difference between the highest and lowest surface roughness observed in Kamling 100 and Marjoko 140, respectively (1.02 vs. 0.21) (Table 1). Flour particle size tends to decrease with surface roughness, but this study did not observe such a consistent trend. Kamling 100 had the largest particle size (137.52) with a 1.02 surface roughness, while Marjoko 140 had the smallest particle size (26.39) (Marjoko 140) with the lowest surface roughness (0.21).

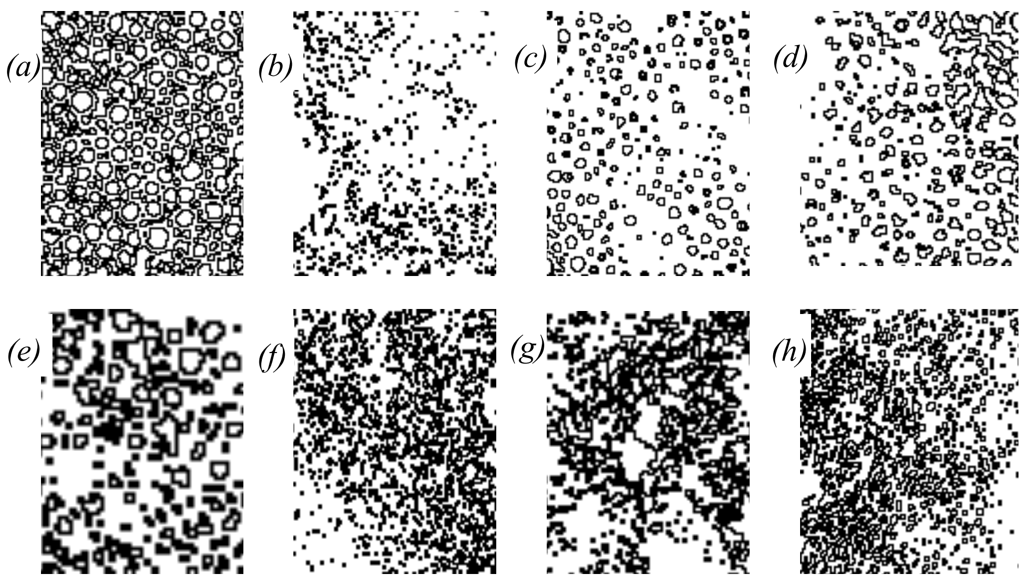

Figure 2. Visualization of the particle shapes of the studied cassava flour (a) Kamling mesh 100, (b) Kamling mesh 140, (c) Marjoko mesh 100, (d) Marjoko mesh 140, (e) Mertega 100, (f) Mertega mesh 140, (g) Slenteng mesh 100, and (h) Slenteng mesh 140

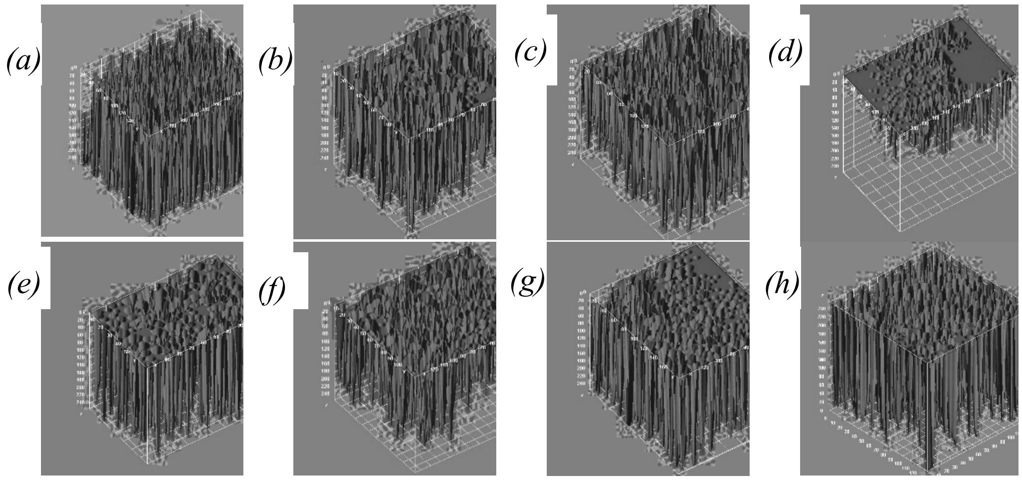

Figure 3. Surface roughness of the studied flour particle (a) Kamling mesh 100, (b) Kamling mesh 140, (c) Marjoko mesh 100, (d) Marjoko mesh 140, (e) Mertega mesh 100, (f) Mertega mesh 140, (g) Slenteng mesh 100, (h) Slenteng mesh140

Color properties

The whiteness index of the cassava flour in this study ranged from 56.68 to 92.76. These results were comparable to 74.63 - 87.33. Statistical analysis revealed that cassava cultivar, particle size, and the interaction of both factors significantly affected the whiteness index of the flour ($p<0.05$). The DMRT analysis showed that Kamling 140 and Mentega 140 had the highest whiteness index and were significantly different from that of other cassava cultivars (Table 1). It indicated that both cultivars are found to be potentially viable for producing cassava flour with an attractive white color that appeals to consumers.

The chroma value of the cassava flour was relatively low, ranging from 1.40 to 3.84, but the most evident in mesh 140 compared to mesh 100. The DMRT results showed that the chroma values of Kamling 140 and Mentega 140 were significantly different from that of Kamling 100 (Table 1). and that the only influential factor to chroma in this study was particle size ($p<0.05$). The hue angle of cassava flour was between 85.51^{o} and 128.19^{o}. In the CIELab color space, this value was approximately in the yellow to greenish yellow position, showing a light and less intense hue. Statistical analysis indicated that the cassava cultivar and the interaction of the cassava cultivar with ith particle size significantly affected the hue angle ($p<0.05$). DMRT analysis showed that the highest and lowest hue angle was observed in Marjoko 100 (125.73^{o}) and

Kamling 100 (85.51°), respectively, indicating a significant difference from other cassava flour in this study.

Discussion

Dimension properties

The particle diameter of the cassava flour across eight treatments ranges from 37.78 to 142.31 μm, which is lower than 50 to 500 μm in common cassava flour reported by Van der Pol *et al*. (2014). It indicates that cassava flour produced in this study has finer granules and expectedly better properties than common cassava. Mirza *et al.* (2022) reported that wheat flour with particle sizes of <125μm exhibited better chemical and rheological properties than coarser flour with 125-150 and 150-180μm particle sizes.

These findings highlighted the importance of cultivar and mesh size when producing cassava flour with specific characteristics suitable for dough production, molding, and baking processes. The starch, protein, and fiber content of different cassava types affect the effectiveness of dough formation, dough shape, and baked products. Flour with finer powder will result in smoother dough and better-baked products, while coarser flour is more suitable for thickening liquids or coating food. Boka *et al.* (2023) found that the functional properties of teff flour were significantly affected by cultivars and particle size, probably due to environmental factors, soil types, and flour particle size due to milling, which was connected to surface area and hence affects the structure of flour components. Another study reported that particle size and variety of grape seed flour affected the moisture, ash, and protein contents of wheat flour and the viscoelasticity of the dough (Iuga *et al.*, 2019). Madene *et al.* (2006) stated that particle size also affects the flavor because the smaller the particle, the quicker the flavor is released. The present study is demonstrated that all flour cassava cultivars from local sources are viable for producing fine cassava flour. According to British Pharmacopoeia, fine and super fine powdered materials can pass mesh 85 and 120 mesh, respectively (Ortega-Rivas, 2012). It was also reported that the finest teff flour particle size demonstrated distinct functional properties compared to flour with larger particle sizes for industrial applications (Boka *et al.*, 2023). Functional properties are important to shape the behavior of foodstuff during preparation and processing qualities (Soans *et al.*, 2023).

The average particle area of cassava flour in this study ranged between 31,171.87 and 213,334.33 μm and was higher than that of wheat flour reported by Yang *et al*. (2022), namely 282.78 to 24,579.37 μm^2. Kandrokov *et al*. (2022) found that the smaller the particle size, the larger the area of flour expressed in a specific volume (cm^2/g). The volume of flour with particle sizes of 140 μm and

<10 µm is 920 cm^2/g vs.14,100 cm^2/g. As the particle size of flour was reduced, the surface area of the flour particles increased, and the volume decreased (Bekele and Amire, 2023), and by extension, the larger the total flour area, the higher the water absorption. It resulted in moister, stickier, and more moldable dough. Flour with a particle diameter <125 µm was reported as the best quality chemical and rheology properties when cooked as a derivative product (Mirza Alizadeh *et al*., 2022).

This result confirmed previous studies that the choice of cassava cultivar and particle size were the key factors in obtaining flour with the desired functional properties. Flour produced from different cassava cultivars had different structures of starch granule, which may affect its frangibility when being milled or sieved, and further results in varied particle sizes and flour surface areas (Vasconcelos *et al*., 2017). A large surface area increases the contact between flour particles and other substances, such as water or additives, which could affect the physical and functional properties of the flour (Akonor *et al*., 2023).

In this study, the number of flour particles is closely related to the size of the particle diameter and the area of cassava flour and is observed in particular areas of the flour. The smaller the particle diameter, the wider the flour area, and the more the flour particles. Hirosawa *et al*. (2021) stated that reducing the particle size would increase the number of particles. The number of these particles was also determined by the impact energy during the cassava flour milling process (Chisenga, 2019). Studies have demonstrated a high variation in particle size and number of particles in the ultrafine dry grinding due to the high impact energy applied to the particles (Chen *et al*., 2015; Guzzo *et al*., 2015; Guzzo *et al*., 2019).

Shape properties

Particle shape substantially determines the engineering behavior of granular materials (Zhao and Wang, 2016) based on sphericity, roundness, and surface roughness. Cruz-Matias *et al*. (2019) state that sphericity is the degree to which a particle approximates the shape of a sphere and is independent of its size. In other words, the closer a particle is to a spherical shape, the closer the sphericity value to be one, and vice versa. According to Zhao and wang (2016), sphericity is one of the most widely used measures of the compactness of a shape. This study confirmed the investigation of wheat flour sphericity in the Southeastern Anatolia Region of Turkey, which is influenced by wheat varieties (Yildrim and Atasoy, 2020). It is probably because each cassava variety naturally bears a distinctive shape in the tissue and cells, producing flour particles with different sphericity during pulverization. Sphericity affects the dough-making process, particularly the particles' ability to flow, disperse, and interact with other ingredients and the biscuit yield (Bellocq *et al*., 2018).

Maroof *et al*. (2020) classify flour particles based on sphericity values into two categories: sphericity (0.60-0.80) and high sphericity (0.8 – 1.0). Most of the flour particles in this study fell into spherical and high spherical particles because they ranged from 0.35-0.98. It was reported that in food applications, particles with a more spherical shape showed substantially improved flowability and dispersibility (Dhiman and Prabhakar, 2021).

Roundness is the measure of the sharpness of a particle's edges and corners (Cruz-Matias *et al*., 2019), and it partly influences particle compactness (Zhao and Wang, 2016), which is crucial to determine the quality of cassava flour. This study has indicated that cassava flour particles tended to have rounded corners rather than sharp. Power's classification chart categorizes particles into six classes based on the roundness values (very angular, angular, subangular, sub-rounded, rounded, well rounded), including rounded particles (0.49-0.70), and well-rounded (0.70-1.0) (Li *et al*., 2021). Based on this classification, the particles of cassava flour produced in this study fell within the categories of rounded and well-rounded groups. Flour particle with a high roundness value has better flowability, dispersibility, and packaging efficiency due to their greater degrees of sphericity (Zhang, 2020). Meanwhile, Udoro *et al*. (2021b) state that particle roundness generally exhibits a greater surface area to volume ratio, which may affect the flour characteristics, such as solubility, reactivity, and sensory properties of the final product. These qualities are essential for various mixing and extrusion processing procedures (Udoro *et al*., 2021b).

In terms of particle surface roughness, the rougher the surface, the lesser the flowability, spreadability, and the flour packing density (Zhang *et al*., 2023). Therefore, the influence of variety and particle size on the surface roughness of flour particles needed to be studied further for three reasons: flowability, spreadability, and packing density. In terms of flowability, rough surfaces create more points of contact between particles, causing them to stick together. This is reduced their ability to flow freely, and the flour is difficult to pour or dispense. Regarding spreadability, rough surfaces increase friction between particles, making it harder for them to slide past each other. This reduces the flour's ability to spread evenly, for example, when dusting a surface or sifting it into a mixture. Lastly, rough surfaces hinder the efficient packing density of particles, leading to lower density and less compact structures. This can affect the texture and stability of food products.

Rahimi *et al*. (2102) reported that decreasing particle size was consistently accompanied by decreasing surface roughness. It may be due to differences in the characteristics of each cassava cultivar, which results in different flour particle sizes after grinding and sieving, where coarser particles tend to have rougher surfaces. Jeong *et al*. (2021) stated that cultivars with high amylose content produce more complex and less breakable particles, resulting in lower roughness (Jeong *et al*., 2021). Maroof *et al*. (2020) adopted the Porter method and BS 812 standard to classify surface roughness into six groups: very rough, rough, relatively rough, corroded, smooth, and glassy. However, this classification lacks exquisite ranges of values for each roughness category, so it is not feasible for the present study. Ahmed (2010) mentions that in addition to particle shape, surface roughness is a substantial parameter in predicting the behavior of particles and powders, which influences the way the particles break, react, sinter, agglomerate, flow, and fluidize. Considering this broad influence, the particle surface roughness of cassava flour particles ranged from 0.21 to 1.02.

Color properties

The Whiteness index of wheat flour undoubtedly has implications on the visual appeal of consumers who tend to choose brighter and whiter cassava flour. Color is crucial in consumer acceptance of food products as it is typically the first perceived sensory aspect (Hasmadi *et al*., 2020b; Marta *et al*., 2024a). Chisenga *et al*. (2020) state that cassava varieties influence dough rheology and bread quality because particle size is a genetic trait that distinguishes one cassava variety from another. The present study is demonstrated that the whiteness index value is contingent upon cassava cultivar and particle size; therefore, selecting the right cassava cultivar is crucial because not all cassava produce flour with a generally desirable white color, which is also reported by Eriksson *et al*. (2014) and Omolola *et al*. (2017). The whiteness index of cassava flour can be improved to meet consumer expectations through a careful selection of cassava cultivars and a thorough examination of the processing parameters (Sánchez *et al*., 2014) and controlled processes (Chisenga *et al*., 2019). This study observes that flour with smaller particle sizes produces a higher whiteness index, indicating that finer particle size results in a whiter color appearance. Accordingly, Anuntagool and Soonthonsun (2023) report that reducing the particle size leads to a significant increase in the whiteness index and that the finest size shows the highest whiteness index.

The chroma value is affected by the material's natural color, in which the more colorful the material, the greater the chroma value. In cassava flour, a lower chroma value indicates a lighter color, which is close to white. Chisenga (2019) reported that the chroma values of flour made of six varieties of cassava were in the range of 6.52–8.16, and significantly different among varieties. Eriksson *et al*. (2014) reported chroma values ranging between 4.96 and 5.17 among three cassava varieties. The present study produced cassava flour with slightly lower chroma values than those studies, indicating whiter cassava flour. Smaller particles showed excellent light scattering efficiency, thus increasing chroma value because every smaller particle has different shapes, and the rough surface area is not exposed to light, nor does it reduce light interaction and reflection (Bala *et al*., 2020). Smaller particles can also accumulate pigments on their surface, resulting in a brighter color appearance. Analyzing chroma value provides valuable information on the production and storage methods that affect the flour color (Gonzalez *et al*., 2020). Acquiring this expertise is critical to maximizing production efficiency and ensuring consistent product quality.

Hue angle is another essential color parameter to describe the color quality of a material. While the hue angle is not directly associated with the final color of cassava flour, the hue angle value helps determine the position of the color combination in the CIELab color space, enabling the estimation of cassava flour color. Eriksson *et al*. (2014) analyzed three varieties of cassava flour and found their hue angle values range from 92.40^o to 93.43^o, which falls in the yellow color position although very faint. Itthivadhanapong and Sangnark (2016) reported that the type of pigment in cassava affects the color angle of the flour due to the variation of carotenoid and anthocyanin pigment composition among cultivars, which is almost the same. These pigments can absorb light at specific wavelengths, affecting the overall color impression.

Based on the CIELab color space, the lowest and highest hue angles obtained in this study fall within the generally light color, indicating that all cultivars and all particle sizes are potentially viable to produce cassava flour. The larger hue angle values of all cultivars are observed at mesh 140 or finer particle sizes. Bala *et al*. (2020) state that the suitable cultivar can reduce particle size, resulting in higher light scattering that potentially changes the color and apparent hue angle (Bala *et al*., 2020).

It is evident that dimensional properties that include particle diameter, total particle area, and number of particles are significantly influenced by cassava cultivar, particle size, and the interaction of both factors. For the shape properties, sphericity is influenced by cassava cultivar, roundness is influenced by particle size, while surface roughness is influenced by cassava cultivar, particle size, and interaction of both factors. For color properties, the whiteness index is affected by cassava cultivar, particle size, and the interaction of both factors. Chroma is affected by particle size, and hue angle is affected by cassava cultivar and the interaction of cassava cultivar and particle size. The results are demonstrated that this study produces finer and whiter cassava flour than the common marketable cassava flour. The sphericity falls within the spherical and high spherical particle categories, and roundness is classified as rounded and well-rounded. There is a tendency for a decrease in particle size to be accompanied by a decrease in surface roughness, and the smaller particle size produces a higher whiteness index. At last, the choice of cassava cultivar and particle size are key factors in producing flour with the desired properties.

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Conflicts of interest

The authors declare no conflict of interest.

References

Afifah, D. N., Ayustaningwarno, F., Febriyanti, F., Nadia, I. P., Ratri, L. K., Rahadiyanti, A. and Pratiwi, S. N. (2024). Characteristics of Red Bean-Mocaf biscuits as alternative high-fiber low-sugar snacks. Progress in Nutrition, 26:1-13.

Ahmed, M. M. (2010). Effect of comminution on particle shape and surface roughness and their relation to flotation process. International Journal of Mineral Processing, 94:180-191.

Akonor, P. T., Osei Tutu, C., Arthur, W., Adjebeng-Danquah, J., Affrifah, N. S., Budu, A. S. and Saalia, F. K. (2023). Granular structure, physicochemical and rheological characteristics of starch from yellow cassava (Manihot esculenta) genotypes. International Journal of Food Properties, 26:259-273.

Akpoghelie, P. O., Edo, G. I., Ali, S. I., Kasar, K. A., Zainulabdeen, K., Mohammed, A. A. and Agbo, J. J. (2024). Effect of processing on the microbiological, proximate, antinutritional and mineral profile of selected yellow cassava varieties and sorghum malt as potential raw materials for alcoholic beverage production. Beverage Plant Research, 4. https://doi.org/10.48130/bpr-0024-0022.

Anuntagool, J. and Soonthonsun, S. (2023). Effect of particle size classification on properties of flour from jack bean: An under-utilized high protein legumes. Lwt, 189:115418.

Auty, M. (2019). tools for product innovation. Microscopy For Food Analysis, 33:51-55.

Azarbad, H. R., Tehrani, M. M. and Rashidi, H. (2019). Optimization of Gluten-Free Bread Formulation Using Sorghum, Rice, and Millet Flour by D-Optimal Mixture Design Approach, 21:101-115.

Barbosa-Canovas, G., Ortega-Rivas, E., Juliano, P. and Yan, H. (2005). Food powders Physical Properties, Processing, and Functionality. Washington State University, United States: Kluwer Academic/Plenum Publishers.

Bagheri, G. (2015). On the characterization of size and shape of irregular particles. Powder Technology, 270:141-153.

Bala, M., Handa, S., D, M. and Singh, R. K. (2020). Physicochemical, functional and rheological properties of grass pea (*Lathyrus sativus* L.) flour as influenced by particle size. Heliyon, 6:e05471.

Bekele, D. W. and Emire, S. A. (2023). Effects of pre-drying treatment and particle sizes on physicochemical and structural properties of pumpkin flour. Heliyon, 9:e21609.

Bellocq, B., Cuq, B., Ruiz, T., Duri, A., Cronin, K. and Ring, D. (2018). Impact of fluidized bed granulation on structure and functional properties of the agglomerates based on the durum wheat semolina. Innovative Food Science and Emerging Technologies, 45:73-83.

Boka, A. L., Tolesa, G. N. and Abera, S. (2023). Effects of variety and particles size on functional properties of Teff (Eragrostis tef (Zucc.) Trotter) flour. Cogent Food and Agriculture, 9.

Cazzaniga, Amanda, Hase, S., Brousse, M. M. and Linares, A. R. (2021). Properties of dehydrated cassava puree and wheat flour blends and its relationship with the texture of doughs. LWT, 136:110310.

Chen, Y., Lian, X., Li, Z., Zheng, S. and Wang, Z. (2015). Effects of rotation speed and media density on particle size distribution and structure of ground calcium carbonate in a planetary ball mill. Advanced Powder Technology, 26:505-510.

Chisenga, S. M., Workneh, T. S., Bultosa, G. and Laing, M. (2019). Proximate composition, cyanide contents, and particle size distribution of cassava flour from cassava varieties in Zambia. AIMS Agriculture and Food, 4:869-891.

Chisenga, S. M. (2019). Progress in research and applications of cassava flour and starch: a review. Journal of Food Science and Technology, 56:2799-2813.

Chisenga, S. M., Workneh, T. S., Bultosa, G., Alimi, B. A. and Siwela, M. (2020). Dough rheology and loaf quality of wheat-cassava bread using different cassava varieties and wheat substitution levels. Food Bioscience, 34:100529.

Cruz-Matías, I., Ayala, D., Hiller, D., Gutsch, S., Zacharias, M., Estradé, S. and Peiró, F. (2019). Sphericity and roundness computation for particles using the extreme vertices model. Journal of Computational Science, 30:28-40.

Gusmao, R. P., Cavalcanti-Mata, M. E. R. M., Duarte, M. E. M. and Gusmão, T. A. S. (2016). Particle size, morphological, rheological, physicochemical characterization and designation of minerals in mesquite flour (Proposis julifrora). Journal of Cereal Science, 69:119-124.

Dewi, S. S. and Widyastuti, T. (2021). Effect of planting time and cassava variety to MOCAF (Modified Cassava Flour) quality level. IOP Conference Series: Earth and Environmental Science, 752.

Dhiman, A. and Prabhakar, P. K. (2021). Micronization in food processing: A comprehensive review of mechanistic approach, physicochemical, functional properties and self-stability of micronized food materials. Journal of Food Engineering, 292:110248.

Eduardo, M., Svanberg, U., Oliveira, J. and Ahrné, L. (2013). Effect of cassava flour characteristics on properties of cassava-wheat-maize composite bread types. International Journal of Food Science, 2013. https://doi.org/10.1155/2013/305407

Eke, J., Achinewhu, S. C., Sanni, L., Barimalaa, I. S., Maziya-Dixon, B. and Dixon, A. (2009). Pasting, color, and granular properties of starches from local and improved cassava varieties in high rainfall region of nigeria. International Journal of Food Properties, 12:438-449.

Engelen, L., De Wijk, R. A., Van Der Bilt, A., Prinz, J. F., Janssen, A. M. and Bosman, F. (2005). Relating particles and texture perception. Physiology and Behavior, 86:111-117.

Eriksson, E., Koch, K., Tortoe, C., Akonor, P. and Baidoo, E. (2014). Physicochemical, Functional and Pasting Characteristics of Three Varieties of Cassava in Wheat Composite Flours. British Journal of Applied Science & Technology, 4:1609-1621.

Falkeisen, A., Gorman, M., Knowles, S., Barker, S., Moss, R. and Mcsweeney, B. (2022). Consumer perception and emotional responses to plant-based cheeses. Food Research International, 158:111513.

Gonzalez, M., Alvarez-Ramirez, J., Vernon-Carter, E. J., Reyes, I. and Alvarez-Poblano, L. (2020). Effect of the Drying Temperature on Color, Antioxidant Activity and In Vitro Digestibility of Green Pea (*Pisum sativum* L.) Flour. Starch/Staerke, 72.

Guzzo, P. L., Tino, A. A. A. and Santos, J. B. (2015). The onset of particle agglomeration during the dry ultra fi ne grinding of limestone in a planetary ball mill. Powder Technology, 284:122-129.

Guzzo, P. L., de Barros, F. B. M., & de Arruda Tino, A. A. (2019). Effect of prolonged dry grinding on size distribution, crystal structure and thermal decomposition of ultrafine particles of dolostone. Powder Technology, 342, 141-148.

Hasmadi, M., Noorfarahzilah, M., Noraidah, H., Zainol, M. K. and Jahurul, M. H. A. (2020a). Functional properties of composite flour: A review. Food Research, 4:1820-1831.

Hasmadi, M., Harlina, L., Jau-Shya, L., Mansoor, A., Jahurul, M. H. and Zainol, M. (2020b). Physicochemical and functional properties of cassava flour grown in different locations in Sabah, Malaysia. Food Research. Retrieved from https://www.myfoodresearch.com/uploads/8/4/8/5/84855864/_7__fr-2019-405_hasmadi.pdf.

Hirosawa, F. H., Wasaki, T. I. and Wata, M. I. (2021). Particle impact energy variation with the size and number of particles in a planetary ball mill. MATEC Web of Conferences 333:02016.

Ikechukwu, A. G. and Oyiza, S. R. (2021). Effects of different tuber crop flours and melon seed meal on the physicochemical and sensory properties of biscuits. Asian Journal of Applied Science and Technology, 05:196-212.

Itthivadhanapong, P. and Sangnark, A. (2016). Effects of substitution of black glutinous rice flour for wheat flour on batter and cake properties. International Food Research Journal, 23:1190-1198.

Iuga, M., Mironeasa, C. and Mironeasa, S. (2019). Oscillatory Rheology and Creep-Recovery Behaviour of Grape Seed-Wheat Flour Dough: Effect of Grape Seed Particle Size, Variety and Addition Level. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Food Science and Technology, 76:40-51.

Jeong, S. (2021). Elucidation of the reduced oil uptake of frying batters made from wheat and brown rice flour blends in terms of rheology and surface roughness. Journal of the Science of Food and Agriculture, 101:6036-6042.

Kandrokov, R. K., Kusova, I. U., Zhukova, D. V, Ryabova, V. N. and Sergey, N. (2022). Centrifugal pneumatic-sieve fractionation of barley and wheat flour for maximum recovery of protein and carbohydrate fractions. Biomedical journal of Scientific and Technical Research, 34174-34179.

Kim, J. M. and Shin, M. (2014). Effects of particle size distributions of rice flour on the quality of gluten-free rice cupcakes. Lwt-Food Science and Technology, 59:526-532.

Kiper, T. and Uzun, O. (2017). Rural development oriented ecotourism planning on catchment basin scale: the case of pabuçdere and kazandere catchment basins. Journal of Agricultural Science and Technology, 19:293-305.

Kohli, D., Jain, A., Singh, O. and Kumar, S. (2023). Gluten free approach of biscuits preparation. Journal of Agriculture and Food Research, 14:100683.

Kouhsari, F., Saberi, F., Lorenzo, M. and Kieliszek, M. (2022). Effect of the various fats on the structural characteristics of the hard dough biscuit. LWT, 159:113227.

Li, L. and Iskander, M. (2021). Evaluation of roundness parameters in use for sand. Journal of Geotechnical and Geoenvironmental Engineering, 147.

Lu, H. (2020). Study on quality characteristics of cassava flour and cassava flour short biscuits. Food Science and Nutrition, 8:521-533.

Madene, A., Jacquot, M., Scher, J. and Desobry, S. (2006). Flavour encapsulation and controlled release - A review. International Journal of Food Science and Technology, 41:1-21.

Marchetti, F. F., da Silva, R. C., Silva, F. O. C. and dos Santos, J. D. (2024). Biocultural elements and multifunctionality of cassava flour production in agrarian reform settlements in the extreme south of Bahia, Brazil. Human Ecology. Retried from https://doi.org/10.1007/s10745-024-00510-8.

Maroof, M. A., Mahboubi, A., Noorzad, A. and Safi, Y. (2020). A new approach to particle shape classification of granular materials. Transportation Geotechnics, 22:100296.

Marta, H., Anastasia, I. L., Cahyana, Y., Filianty, F., Fetriyuna. and Sondari, D. (2024a). Evaluation of pasting and functional properties of composite flour from Indonesian local tubers and its application in gluten-free biscuits. Journal of Food Measurement and Characterization, 18:1-11.

Marta, H., Yusnia, S. A., Fetriyuna, F., Arifin, H. R., Cahyana, Y. and Sondari, D. (2024b). Application of flour blends from modified cassava and suweg flours in gluten-free steamed brownies. Polish Journal of Food and Nutrition Sciences, 74:188-196.

Mirza Alizadeh, A., Peivasteh-Roudsari, L., Tajdar-Oranj, B., Beikzadeh, S., Barani-Bonab, H. and Jazaeri, S. (2022). Effect of flour particle size on chemical and rheological properties of wheat flour dough. Iranian Journal of Chemistry and Chemical Engineering, 41:682-694.

Monthe, O. C., Grosmaire, L., Nguimbou, R. M., Dahdouh, L., Ricci, J., Tran, T. and Ndjouenkeu, R. (2018). Rheological and textural properties of gluten-free doughs and breads based on fermented cassava, sweet potato and sorghum mixed flours. LWT - Food Science and Technology. LWT, 101.

Nammakuna, N., Suwansri, S., Thanasukarn, P. and Ratanatriwong, P. (2009). Effects of milling type and flour particle size on rice cracker qualities. 11th Asean Food Conference 2009, (January).

Noort, M. W. J., Renzetti, S., Linderhof, V., du Rand, G. E., Marx-Pienaar, N. J. M. M., de Kock, H. L. and Taylor, J. R. N. (2022). Towards sustainable shifts to healthy diets and food security in sub-saharan africa with climate-resilient crops in bread-type products: a food system analysis. Foods, 11.

Omolola, A. O., Kapila, P. F., Anyasi, T. A., Jideani, A. I. O. and Mchau, G. A. (2017). Optimization of color and thermal properties of sweet cassava (*Manihot esculenta* Crantz Var. UVLNR 0005) Flour Using Response Surface Methodology. Asian Journal of Agricultural Research, 11:57-65.

Ortega-Rivas, E. (2012). Unit operation of particulate solids theory and practice. in taylor and francis group (Vol. 11). CRC Press-Taylor & Francis Group,6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487-2742 p.

Oyeyinka, S. A., Adeloye, A. A., Smith, S. A., Adesina, B. O. and Akinwande, F. F. (2019). Physicochemical properties of flour and starch from two cassava varieties. Agrosearch, 19:28-45.

Rahimi, M., Aslani, M. R. and Rezai, B. (2012). Influence of surface roughness on flotation kinetics of quartz. Journal of Central South University of Technology (English Edition), 19:1206-1211.

Rahmawati, R. S., Fathoni, A., Sukma, D., Ardie, S. W. and Sudarsono, S. (2024). Assessment of yellow and white fleshed cassava tuberous root cultivars reveals different responses to post-harvest physiological deterioration. Journal of Tropical Crop Science, 11:64-73.

Ratnawati, L. and Desnilasari, D. (2020). Characterization of modified cassava flour (mocaf)-based biscuits substituted with soybean flour at varying concentrations and particle sizes. Food Research, 4:645-651.

Renzetti, S., Aisala, H., Ngadze, R. T., Linnemann, A. R. and Noort, M. W. (2023). Bread products from blends of african climate resilient crops: baking quality, sensory profile and consumers' perception. Foods, 12.

Sánchez, T., Dufour, D., Moreno, J. L., Pizarro, M., Aragón, I. J., Domínguez, M. and Ceballos, H. (2013). Changes in extended shelf life of cassava roots during storage in ambient conditions. Postharvest Biology and Technology, 86:520-528.

Sellam, A., Zerrouki, Y., Dali, M., Maleb, A., Khalid, I., Hamdaoui, N. and Meziane, M. (2024). In vitro antioxidant properties of lactobacillus gasseri isolated from fermented milk: Isolation and preparation of strains and intracellular cell-free extracts, chemical testing (Hydrogen Peroxide, Superoxid). Indonesian Journal of Science & Technology 9:611-622.

Sigüenza-Andrés, T., Gallego, C. and Gómez, M. (2021). Can cassava improve the quality of gluten free breads? Lwt, 149:111923.

Soans, J. C., Pavithra, M. and Sridhar, K. R. (2023). Nutritional evaluation of banana inflorescence and development of food products. International Journal of Agricultural Technology, 19:2651-2668.

Tappiban, P., Sraphet, S., Srisawad, N., Wu, P., Han, H., Smith, D. R. and Triwitayakorn, K. (2020). Effects of cassava variety and growth location on starch fine structure and physicochemical properties. Food Hydrocolloids, 108.

Udoro, E. O., Anyasi, T. A. and Jideani, A. I. O. (2021). Process-Induced Modifications on Quality Attributes of Cassava (*Manihot esculenta* Crantz) Flour. Processes, 9:1891.

Van der Pol, E., Coumans, F. A. W., Grootemaat, A. E., Gardiner, C., Sargent, I. L., Harrison, P. and Nieuwland, R. (2014). Particle size distribution of exosomes and microvesicles determined by transmission electron microscopy, flow cytometry, nanoparticle tracking analysis, and resistive pulse sensing. Journal of Thrombosis and Haemostasis, 12:1182-1192.

Vasconcelos, L. M., Brito, A. C., Carmo, C. D., Oliveira, P. H. G. A. and Oliveira, E. J. (2017). Phenotypic diversity of starch granules in cassava germplasm. Genetics and Molecular Research, 16:1-15.

Wambua, M. K. (2017). Effect of variety and maturity stage of cassava (*Manihot esculenta*) on flour properties and sensory characteristics of wheat-cassava composite bread (Doctoral dissertation, Egerton University).

Yang, L., Wang, S., Zhang, H., Du, C., Li, S. and Yang, J. (2022). Effects of black soybean powder particle size on the characteristics of mixed powder and wheat flour dough. Lwt, 167:113834.

Yildrim, A. and Atasoy, A. (2020). Quality characteristics of some durum wheat varieties grown in Southeastern Anatolia Region of Turkey (GAP). Harran Tarım ve Gıda Bilimleri Dergisi, 24:420-431.

Zhang, P., Zhongnan Bi, Hongyao Yu, Wang, R., Guangbao Sun. and Shaoming Zhang (2023). Effect of particle surface roughness on the flowability and spreadability of Haynes 230 powder during laser powder bed fusion process. Journal of Materials Research and Technology, 26:4444-4454.

Zhang, Y. (2020). Impacts of environmental factors on pasting properties of cassava flour mediated by its macronutrients. Frontiers in Nutrition, 7.

Zhao, B. and Wang, J. (2016). 3D quantitative shape analysis on form, roundness, and compactness with μCT. Powder Technology, 291:262-275.

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