

# Techno-functional Properties of Fava Bean (*Vicia faba* L.) Pod Flour as a Function of the Drying Process

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The by-product of fava bean processing, mainly the pods, accounts for more than 70% by weight of the vegetable, with the consequent problem from an economic and environmental point of view. Thinking of its richness in nutritional and bioactive compounds, proposing an integrated zero-waste process for the recovery of fava bean pods as a powdered food ingredient would contribute to a healthy, intelligent and sustainable diet. Freeze-drying (FD) can be proposed as the most appropriate reference method when dehydrating raw materials of plant origin, with thermolabile and oxidation-sensitive compounds. However, if the major bioactive compound is not vitamin C, but phenols, e.g., as is the case in fava bean pods, this benefit may not be as evident. Hot air drying (AD) is one of the most common methods of food preservation and significantly cheaper than FD. In any case, techno-functional properties of the powder should also be considered. As such a powdered product, it must respond to adequate flowability. In addition, its use as a food ingredient must allow for an adequate capacity for interaction with water and oil. This study compares different techno-functional properties of the powder obtained by applying both drying processes, at 45°C, 50°C and 55°C. The drying temperature had practically no effect on most of the properties analyzed. AD allowed to obtain a product with a larger particle size and lower interparticle porosity than FD, which led to a slightly lower hygroscopicity, better flowability and wettability, and also higher emulsifying activity and emulsion stability, despite a lower oil retention capacity. These results allow us to recommend, among the studied methods, AD at 55°C as the quickest process to obtain a fava bean POD flour with adequate technofunctional properties.

## 1. Introduction

The economic and social progress of the last century, accompanied by its negative environmental impact, points to a necessary change in the way food is produced and consumed, not only to contribute to improving human health, but also to increasing productivity and sustainability. In this sense, the challenge posed to today's society to have natural foods and ingredients that are attractive to different population groups, easy and convenient to handle and consume, of high quality, safe, healthy and environmentally friendly, becomes a fundamental challenge for food technologists and engineers, who have to innovate in the design of food processes to respond to this demand. With this approach, it is necessary to contribute to the proposal of processing lines that minimize the generation of by-products. The industries dedicated to the processing of vegetable foodstuffs are among those that generate the greatest amount of them, in many cases exceeding 50% of the raw material. Considering that this biomass is rich in nutrients and other bioactive compounds, which are of great interest for their health benefits (Helkar et al., 2016), its valorization for human food is a challenging field of study that aims to ensure environmental protection, foster economic development and, at the same time, contribute to a sustainable and healthy diet.

The high water content of by-products of plant origin makes them highly unstable. One way to extend its shelf life is by drying, which would make it possible to offer a powdered food ingredient with the advantages of stability, handling and logistics that this format entails. Freeze-drying is proposed as the process that allows obtaining better quality products, especially when processing raw materials with thermolabile and oxidation-sensitive

compounds such as those of vegetable origin. However, it is a long and energy-intensive process. On the other hand, air drying is one of the most common and significantly cheaper methods of food preservation, which, moreover, can even be applied in any household. However, the temperatures reached by the products, often over a long period of time, can be responsible for significant quality losses related to changes in color, aroma, flavor, nutritional value and potentially functional value. In any case, the techno-functional properties of the powdered ingredients obtained are no less important, both those related to the interaction of the particles with air, which are essential during handling, and with water or oil, as the most frequent means of reconstitution prior to consumption.

Worldwide bean production generates around 70% by-product after processing into seed for human consumption (Valente et al., 2018). Fava bean pod is an excellent source of fiber, protein, minerals and essential amino acids, and also contains polyunsaturated fatty acids and phenolic compounds, which confer anti-inflammatory, antimicrobial and antioxidant properties (Mejri et al., 2018). However, unlike other agricultural by-products, the potential of broad bean pods to be consumed as food is underexploited. This study compares bean pod flour obtained by freeze-drying (FD) and air drying (AD), applied at different temperatures, in order to recommend the drying process that offers the best price-quality ratio. In addition, the incorporation of gum Arabic (GA) as a biopolymer is also envisaged to help delay the caking phenomena of the powder and its physical stability. To ensure the success of the ingredient obtained from the bean pod, it seems appropriate to know some properties of interest from a technological point of view, including its flowability, or ability to remain as a loose powder without agglomeration, allowing easy handling, and its ability to mix with water or oil, which are the components with the highest presence in foods to which the proposed powdered ingredient could be added.

## 2. Material and methods

### 2.1 Obtaining the flour from bean pods

The raw material used was washed and blanched fava bean pods, provided by Sol y Tierra Campo de Cartagena, SL (Torre Pacheco, Murcia, Spain), crushed in an emulsifier (Robot Coupe Blixer 2, Vincennes, France) and formulated with 0.225 g GA/ g fava bean purée (dry basis, db) (Scharlab, Valencia, Spain). The mixtures obtained were dehydrated and milled to obtain the different flours. Dehydration was carried out by AD (GRAEF DA506, Barcelona, Spain) and by FD (Telstar Lyoquest-55 L, Terrasa, Spain), fitted to 5 Pa and -55 °C condenser temperature). The formulated puree was arranged in 0.5 cm thick aluminum trays and dehydrated at three temperatures in each case (45, 50 and 55 °C), until a water content of less than 5 % was achieved, which is characteristic of other pulse flours. Prior to drying by FD, the samples were frozen at -45 °C for 48 h. Grinding of the dehydrated samples was carried out at 15000 rpm for 30 seconds with the aid of an ultracentrifugal mill (Retsch GmbH ZM 300, Haan, Germany), using an annular sieve of 80 µm (Retsch GmbH, Haan, Germany). The obtained flours were stored under refrigeration in zip bags until analysis.

### 2.2 Analytical determinations of powdered bean pods

The 6 fava bean flour samples obtained were characterized in terms of their particle size distribution and analyzed for different techno-functional properties related to their flowability and their ability to interact with water and oil. All determinations were carried out in triplicate.

The particle size distribution was carried out by sieving, using sieves of 50 mm diameter and 90, 63, 53, 45, 38, 32 and 25 µm mesh size, with their corresponding lid and bottom (CISA Cedacería Industrial, Lliça de Vall, Barcelona, Spain), with the help of a vibrating drum (AMPO.40 CISA, Cedacería Industrial S.L, Lliça de Vall, Barcelona, España). 20 g of each flour was sieved at 50 Hz and 2.5 mm amplitude for 5 min and the amount of sample retained on each sieve was recorded. Relative frequency (%) and mean particle size (MPS) were calculated by applying Eq(1) and Eq(2), respectively. In addition, the mode and median were characterized, these being the parameters related to the size that accumulates more particles and the one that leaves 50% of particles above and below it, respectively.

$$\text{Relative frequency (\%)} = \frac{m_s}{m} \cdot 100 \quad (1)$$

$$\text{MPS (\mu m)} = \frac{\sum_s (M_s \cdot m_s)}{m} \quad (2)$$

Where  $m_s$  is the mass of sample retained on each sieve (g),  $m$  is the total sieved sample mass (g),  $M_s$  is the mean of the mesh size of the sieve on which the sample is retained and the previous one (µm), and MPS is the mean particle size (µm).

To evaluate the flowability of the flours, the methodology described by Uscanga et al. (2020) was used to analyze the angle of repose ( $\alpha$ ), the apparent porosities of the poured ( $\epsilon_p$ ) and tapped ( $\epsilon_t$ ) powders, the Hausner Index (HI) and the Carr Index (CI). To determine the ability of the flours to interact with water, the hygroscopicity, wettability, dispersibility, solubility, water retention capacity (WRC) and foam capacity and stability (FC and FS, respectively) were analyzed. For the latter, the methodology used in all cases was the one proposed by Martínez-Navarrete et al. (2023) except for wettability (Standard ISO/TS 17758/IDF 087, 2014) and hygroscopicity (Camacho et al., 2021). To determine possible interaction between flours and oil, the oil retention capacity (ORC, Garau et al., 2007) and the emulsifying activity and stability (EA and EE, respectively) were determined (Martínez-Navarrete et al., 2023).

### 2.3 Statistical analysis

A multifactorial ANOVA was performed with two factors, the drying type (FD and AD) and the drying temperature (45 °C, 50 °C, and 55 °C). Differences with a p-value < 0.05 were considered significant. Statistical data processing was carried out using Statgraphics Centurion XVII software under license from the Universitat Politècnica de València.

### 3. Results and discussion

Figure 1 shows the particle size distribution of the six flours studied, obtained from the weight of the sample retained on each sieve with respect to the total sieved sample (relative frequency), and Table 1 shows the parameters considered for the characterisation of the particle size distribution. As shown in Fig. 1, the particle size distribution of the LIO samples was more homogeneous. The flours obtained by SAC had more particles with larger particle sizes and fewer with smaller ones.

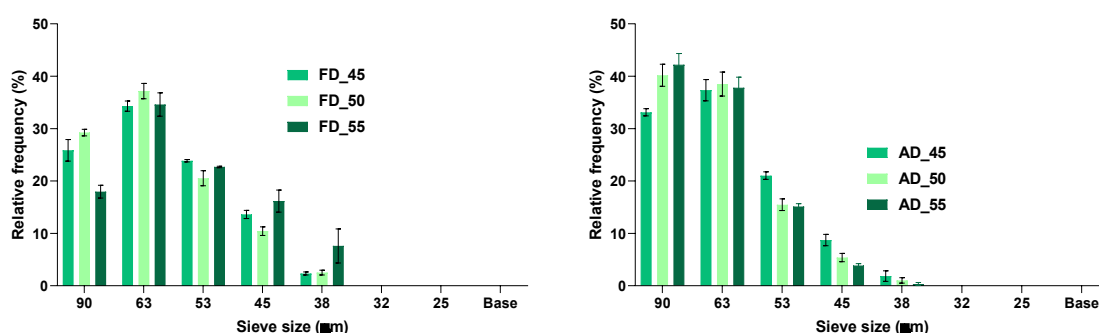


Figure 1: Particle size distribution of samples obtained by freeze-drying (FD) and air drying (AD), at 45, 50 and 55 °C, as a percentage of the sample retained on each of the sieves (relative frequency).

Table 1: Mean particle size (MPS), median, and mode of samples obtained by freeze-drying (FD) and air drying (AD) at 45, 50, and 55 °C, expressed as  $\bar{x} \pm \sigma$ .

		45 °C	50 °C	55 °C
MPS (µm)	FD	64.6±0.7 <sup>(Ba)</sup>	66.3±0.5 <sup>(Ba)</sup>	60.8±1.5 <sup>(Aa)</sup>
	AD	67.7±0.4 <sup>(Ab)</sup>	71.0±0.3 <sup>(Bb)</sup>	72.2±0.5 <sup>(Bb)</sup>
Median (µm)	FD	73.00±1.03 <sup>(Ba)</sup>	76.836±0.998 <sup>(Ca)</sup>	67±3 <sup>(Aa)</sup>
	AD	78.9±0.9 <sup>(Ab)</sup>	84.4±0.7 <sup>(Bb)</sup>	85.81±1.01 <sup>(Bb)</sup>
Mode (µm)	FD	63 <sup>(Aa)</sup>	63 <sup>(Aa)</sup>	63 <sup>(Aa)</sup>
	AD	63 <sup>(Aa)</sup>	81±16 <sup>(Bb)</sup>	90 <sup>(Bb)</sup>

Different letters in upper case (A,B) or lower case (a,b) indicate significant differences ( $p < 0.05$ ) between the temperature (45, 50 or 55 °C) or the drying process (FD or AD), respectively.

As observed in Table 1, FD yields flours with a lower MPS and median than AD ( $p < 0.05$ ). This may be mainly due to the fact that the freeze-dried product is easier to grind as it is more porous and does not suffer from crusting. On the other hand, a higher temperature during FD seems to result in an even more porous product, whereas in the case of AD, it would lead to a higher crusting of the product, which would offer more resistance to crushing. The mode was significantly greater in the case of AD samples obtained at the higher temperatures. Table 2 shows the results of the analysed physical properties related to the powder particles' flowability. These properties influence the behaviour of the powder during handling, after processing. The looser the particles of a

powdered product are and the better they flow in the air, the lower the HI, CI and  $\alpha$ . Temperature did not influence any of these three parameters and, although, according to their values, all products showed an acceptable behaviour (Alavi, 2005; Barbosa-Cánovas et al., 2005; Fitzpatrick, 2013), the flowability of AD flours, with larger particle size, was better than that of FD flours. This is consistent with some studies that associate larger particle size with better particle flow of a powder (Zhou et al., 2001). In addition, the lower porosity of the AD samples can also contribute to their better flowability, which allows better accommodation of the particles.

*Table 2: Mean value  $\pm$  standard deviation of the angle of repose ( $\alpha$ ), porosities: poured ( $\epsilon_p$ ) and tapped ( $\epsilon_t$ ), Hausner index (HI) and Carr index (CI) analysed to the samples obtained by freeze-drying (FD) and air drying (AD), at 45, 50 and 55 °C.*

		45 °C	50 °C	55 °C
$\alpha$ (°)	FD	46 $\pm$ 3 <sup>(Aa)</sup>	45 $\pm$ 2 <sup>(Aa)</sup>	44 $\pm$ 4 <sup>(Aa)</sup>
	AD	41.5 $\pm$ 0.9 <sup>(Ab)</sup>	42 $\pm$ 2 <sup>(Ab)</sup>	43.7 $\pm$ 1.5 <sup>(Ab)</sup>
$\epsilon_p$ (%)	FD	70.5 $\pm$ 0.8 <sup>(Aa)</sup>	69.0 $\pm$ 1.3 <sup>(Aa)</sup>	68.8 $\pm$ 0.7 <sup>(Aa)</sup>
	AD	55.7 $\pm$ 0.6 <sup>(Ab)</sup>	53.0 $\pm$ 0.7 <sup>(Bb)</sup>	57.1 $\pm$ 1.2 <sup>(Ab)</sup>
$\epsilon_t$ (%)	FD	65.3 $\pm$ 0.3 <sup>(Aa)</sup>	66.5 $\pm$ 0.8 <sup>(Aa)</sup>	65.6 $\pm$ 1.6 <sup>(Aa)</sup>
	AD	50.5 $\pm$ 3.0 <sup>(Ab)</sup>	48.2 $\pm$ 1.4 <sup>(Ab)</sup>	52.5 $\pm$ 1.0 <sup>(Ab)</sup>
HI	FD	1.18 $\pm$ 0.03 <sup>(Aa)</sup>	1.08 $\pm$ 0.02 <sup>(Aa)</sup>	1.10 $\pm$ 0.04 <sup>(Aa)</sup>
	AD	1.12 $\pm$ 0.06 <sup>(Aa)</sup>	1.103 $\pm$ 0.014 <sup>(Aa)</sup>	1.107 $\pm$ 0.007 <sup>(Aa)</sup>
CI (%)	FD	0.15 $\pm$ 0.02 <sup>(Aa)</sup>	0.08 $\pm$ 0.02 <sup>(Aa)</sup>	0.09 $\pm$ 0.04 <sup>(Aa)</sup>
	AD	0.10 $\pm$ 0.05 <sup>(Aa)</sup>	0.093 $\pm$ 0.012 <sup>(Aa)</sup>	0.097 $\pm$ 0.006 <sup>(Aa)</sup>

Different letters in upper case (A,B) or lower case (a,b) indicate significant differences ( $p < 0.05$ ) between the temperature (45, 50 or 55 °C) or the drying process (FD or AD), respectively.

The properties related to the interaction of the powders with water appear in Table 3. AD flours were less hygroscopic than FD samples ( $p < 0.05$ ), which could be considered non-hygroscopic and slightly hygroscopic, respectively (Schuck et al., 2012). Significant differences were observed in the wettability, much lower (longer wetting time) in the case of the samples obtained by FD. This difference may be related to the different MPS of the samples, the lower the size (FD samples), the greater the surface exposed to the environment, thus favoring the interaction with the water present there. This promotes water adsorption and the formation of liquid bridges between the particles, leading to a tendency to agglomerate on the surface of the liquid, which increases the time required for wetting (Schubert, 1987; O'Donoghue et al., 2019).

*Table 3: For the samples obtained by freeze-drying (FD) and air drying (AD), at 45, 50 and 55 °C, mean value  $\pm$  standard deviation of hygroscopicity (g water gained/100 g dry solutes), water retention capacity (WRC, g water/100 g dry residue), wettability (s), solubility (g soluble solutes/100 g total solutes), dispersibility (g ss passing the sieve/100 g dry solutes) and foaming capacity and stability (FC and FS, respectively).*

		45 °C	50 °C	55 °C
Hygroscopicity	FD	4.90 $\pm$ 0.10 <sup>(Aa)</sup>	4.3 $\pm$ 0.2 <sup>(Aa)</sup>	4.4 $\pm$ 0.3 <sup>(Aa)</sup>
	AD	3.00 $\pm$ 0.10 <sup>(Ab)</sup>	3.2 $\pm$ 0.1 <sup>(Ab)</sup>	3.0 $\pm$ 0.6 <sup>(Ab)</sup>
Wettability	FD	1976 $\pm$ 245 <sup>(Aa)</sup>	1712 $\pm$ 454 <sup>(Aa)</sup>	1368 $\pm$ 52 <sup>(Aa)</sup>
	AD	304 $\pm$ 40 <sup>(Ab)</sup>	369 $\pm$ 69 <sup>(Ab)</sup>	524 $\pm$ 101 <sup>(Ab)</sup>
Dispersibility	FD	8.4 $\pm$ 0.8 <sup>(Aa)</sup>	10.2 $\pm$ 0.8 <sup>(Aa)</sup>	9.2 $\pm$ 0.7 <sup>(Aa)</sup>
	AD	10.2 $\pm$ 0.4 <sup>(Aa)</sup>	9.2 $\pm$ 1.0 <sup>(Aa)</sup>	9.4 $\pm$ 0.4 <sup>(Aa)</sup>
Solubility	FD	51.8 $\pm$ 0.7 <sup>(Aa)</sup>	47 $\pm$ 2 <sup>(Ba)</sup>	50.3 $\pm$ 0.4 <sup>(Aa)</sup>
	AD	49.0 $\pm$ 1.6 <sup>(Ab)</sup>	45 $\pm$ 4 <sup>(Bb)</sup>	48 $\pm$ 3 <sup>(Ab)</sup>
WRC	FD	5.95 $\pm$ 0.19 <sup>(Ab)</sup>	5.58 $\pm$ 0.09 <sup>(Bb)</sup>	5.83 $\pm$ 0.13 <sup>(Aa)</sup>
	AD	6.9 $\pm$ 0.2 <sup>(Aa)</sup>	6.2 $\pm$ 0.2 <sup>(Ba)</sup>	6.0 $\pm$ 0.2 <sup>(Ba)</sup>
FC (%)	FD	6.1 $\pm$ 1.3 <sup>(Aa)</sup>	9 $\pm$ 3 <sup>(Aa)</sup>	7.4 $\pm$ 1.6 <sup>(Aa)</sup>
	AD	7.8 $\pm$ 1.3 <sup>(Aa)</sup>	5 $\pm$ 2 <sup>(Ab)</sup>	3.5 $\pm$ 1.1 <sup>(Ab)</sup>
FS (%)	FD	104.1 $\pm$ 1.4 <sup>(Aa)</sup>	107 $\pm$ 2 <sup>(Aa)</sup>	102.4 $\pm$ 1.2 <sup>(Aa)</sup>
	AD	104.0 $\pm$ 3.7 <sup>(Aa)</sup>	100.8 $\pm$ 1.4 <sup>(Ab)</sup>	100.4 $\pm$ 0.7 <sup>(Ab)</sup>

Different letters in upper case (A,B) or lower case (a,b) indicate significant differences ( $p < 0.05$ ) between the temperature (45, 50 or 55 °C) or the drying process (FD or AD), respectively.

Dispersibility was not affected by the process (Table 3). On the other hand, FD samples showed higher solubility and lower WRC, which may be related to their greater porosity (Table 2). Nevertheless, for WRC this effect was

not significant ( $p>0.05$ ) at 55 °C. FC and FS were affected by the process at 50 and 55 °C, both properties being more favorable for the FD samples. A higher crusting of the flours obtained by AD at higher temperatures could justify this result. The drying temperature only influences solubility and WRC and with an unclear pattern. The composition of the fava bean would affect the interaction of flour with water, mainly its content in protein and fibre (13.81 and 57.46 g/ 100 g db, respectively, Mejry et al., 2018). Increasing the drying temperature may affect the protein structure by promoting the migration of hydrophobic groups towards the surface, which would justify the lower solubility and WRC observed at 50 °C when compared to 45 °C. However, at 55 °C, the higher solubility of the fibre also present in bean pod flour could justify the observed increase in solubility in this case, with no more effect in WRC of AD sample. For each drying process, temperature did not affect the FC and FS. Table 4 shows the properties of the powder related to its interaction with the oil. As for ORC, the values obtained were lower than those of WRC, which could be related to the presence in this product of a high number of hydrophilic groups capable of binding to water molecules, and to the presence of soluble fibres that have a high water absorption capacity (Mokhtar et al., 2018; Thebaudin et al., 1997). The ORC of the FD samples was higher than that of the AD samples. This may be due to the higher porosity of the FD samples (Gao et al., 2020) and also to the higher crusting of the AD samples, more intense at the highest temperature ( $p<0.05$ ). No differences in EA were observed with either drying method or temperature, although the former did affect ES. As described by Nushtaeva (2016), the larger particle size of AD flours could account for this higher stability.

*Table 4: Mean value  $\pm$  standard deviation of oil retention capacity (ORC) and emulsifying activity and stability (EA and ES, respectively) for the samples obtained by freeze-drying (FD) and air drying (AD), at 45, 50 and 55 °C.*

		45 °C	50 °C	55 °C
ORC (g/100 g)	FD	1.09 $\pm$ 0.07 <sup>(Aa)</sup>	0.98 $\pm$ 0.05 <sup>(Aa)</sup>	0.99 $\pm$ 0.04 <sup>(Aa)</sup>
	AD	0.85 $\pm$ 0.06 <sup>(Ab)</sup>	0.84 $\pm$ 0.05 <sup>(Ab)</sup>	0.75 $\pm$ 0.03 <sup>(Bb)</sup>
EA (%)	FD	6.0 $\pm$ 0.9 <sup>(Aa)</sup>	6.7 $\pm$ 0.3 <sup>(Aa)</sup>	6.65 $\pm$ 0.13 <sup>(Aa)</sup>
	AD	6.6 $\pm$ 0.2 <sup>(Aa)</sup>	6.90 $\pm$ 0.08 <sup>(Aa)</sup>	6.7 $\pm$ 0.2 <sup>(Aa)</sup>
ES (%)	FD	5.8 $\pm$ 1.0 <sup>(Aa)</sup>	5.6 $\pm$ 0.2 <sup>(Aa)</sup>	6.1 $\pm$ 0.7 <sup>(Aa)</sup>
	AD	8.8 $\pm$ 0.6 <sup>(Ab)</sup>	7.9 $\pm$ 0.7 <sup>(Ab)</sup>	7.9 $\pm$ 0.3 <sup>(Ab)</sup>

Different letters in upper case (A,B) or lower case (a,b) indicate significant differences ( $p<0.05$ ) between the temperature (45, 50 or 55 °C) or the drying process (FD or AD), respectively.

#### 4. Conclusions

The results of this study seem to show a significant influence of the drying method on the properties studied. The effect of the process seems to be a consequence of the different structure of the dried matrix. FD resulted in more porous products, making them easier to grind. On the other hand, AD results in the formation of a surface crust, more intense at higher temperatures, which makes the product more resistant to crushing. This results in flour particles of larger size and lower interparticle porosity when obtained by AD. Because of this, although all the flours showed acceptable flowability and low hygroscopicity, which are desirable characteristics in this type of product, these properties were improved in the ADs, which, in addition, exhibited much shorter wetting time, lower ORC, and higher emulsion stability. The flours obtained by FD showed higher solubility, and at the highest temperatures, also higher foaming capacity and foam stability than the ADs. On the other hand, although some significant differences in solubility, WRC, and ORC due to temperature are observed, the values were very similar due to the high reproducibility of the measurements. Temperature does not significantly affect the other measured properties. With these results, thinking about the design of a versatile, high quality, easy to obtain and, possibly, lower cost ingredient, it seems more advisable to use hot air drying, at 55 °C, to shorten the duration of the process. This process would be especially recommended if the powdered ingredient is to be used for the formulation of emulsions. Only for the formulation of foams, it could be considered to obtain the flour by freeze-drying at 55 °C.

#### Nomenclature

AD – Hot air drying

CI – Carr Index, %

EA – Emulsifying activity, %

ES – Emulsifying stability, %

FC – foam capacity, %

FD – Freeze-drying

FS – foam stability, %

GA – Gum Arabic, %

HI – Hausner Index, -

MPS – Mean particle size,  $\mu\text{m}$

ORC – Oil retention capacity, %

WRC – Water retention capacity, %

$\alpha$  – Angle of repose, °

$\varepsilon_p$  – Apparent porosity of the poured powder, %

$\varepsilon_t$  – Apparent porosity of the tapped powder, %

## Acknowledgments

This work is part of [PID2022-139711OB-C21] R&D&i Project. The authors appreciate the financial support offered by Ministerio de Ciencia e Innovación/Agencia Estatal de Investigación/10.13039/501100011033/; and “Fondo Europeo de Desarrollo Regional Una manera de hacer Europa”.

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