Draft Manuscript for Review

RESISTANT MALTODEXTRIN'S EFFECT ON THE PHYSICOCHEMICAL AND STRUCTURE PROPERTIES OF SPRAY DRIED ORANGE JUICE POWDERS

Journal:	*European Food Research and Technology*
Manuscript ID	EFRT-20-1470
Manuscript Type:	Original paper
Date Submitted by the Author:	07-Oct-2020

Complete List of Authors:	Igual, Marta; Universidad Politécnica de Valencia, Food Technology García-Segovia, Purificación; Universidad Politécnica de Valencia, Food technology Martínez-Monzó, Javier; Universidad Politécnica de Valencia, Food Technology

Keywords:	resistant maltodextrin, colour, microstructure, spray drying, orange juice

RESISTANT MALTODEXTRIN'S EFFECT ON THE PHYSICOCHEMICAL AND STRUCTURE PROPERTIES OF SPRAY DRIED ORANGE JUICE POWDERS

Marta Igual*, Purificación García-Segovia, Javier Martínez-Monzó

Universitat Politècnica de València, Food Technology Department, Food Investigation and Innovation Group, Camino de Vera s/n, 46022 Valencia, Spain

Corresponding author. Tel.: +34963877361, E-mail address: marigra@upvnet.upv.es *(M. Igual).*

Authors ORCID code

Marta Igual: 0000-0001-5128-5489

Purificación García-Segovia: 0000-0002-4968-5050

Javier Martínez-Monzó: 0000-0002-1123-2304

Abstract:

Resistant maltodextrin (RMD), derived from the heat treatment of corn starch, is a water-soluble fermentable functional fibre. Its benefits include being a satiating prebiotic, reducer of glucose and triglycerides in the blood, and promoter of good gut health. Despite its functionality, there is still further need for investigations of its use as a food formulating ingredient and their physicochemical property changes. This study aimed to evaluate the effect of RMD addition on the physicochemical and structural properties of spray dried orange juice powders. The physicochemical properties evaluated were water content, hygroscopicity, bulk density, porosity, water solubility, water absorption index, colour, and microstructure. We found RMD addition improved the orange juice spray dried powder productivity. Samples with RMD were more porous and less hygroscopic, and they presented low water content; physicochemical properties desirable for powders. Therefore, to reach a compromise between powders' functionality and physicochemical property changes, especially colour, the addition of 5 RMD% is recommended.

Keywords: resistant maltodextrin; colour; microstructure; spray drying; orange juice

Declarations:

Funding

Not applicable

Conflict of interest

The authors declare no conflict of interest.

Availability of data and material

Not applicable

Code availability

Not applicable

Author Contributions

Conceptualisation, M.I, P.G-S. and J. M-M.; methodology, M.I.; formal analysis, M.I..; investigation, M.I and P.G-S.; resources, P.G-S.; data curation, M.I. and P.G-S.; writing—original draft preparation and editing, M.I.; writing—review, P.G-S. and J. M-M; supervision, J.M-M.; project administration, P.G-S.; funding acquisition, P.G-S. and J. M-M. All authors have read and agreed to the published version of the manuscript.

1. Introduction

Fruits have historically been considered rich sources of essential dietary micronutrients and fibres. Moreover, they have been recognised as important sources for an array of phytochemicals that individually, or in combination, may benefit health [1]. Frequent consumption of fruits and vegetables is associated with a lowered risk of cancer, heart disease, hypertension, and stroke [2-4]. Among fruits, citrus juice is an important dietary source of bioactive compounds, whose beneficial health effects are ascribed to its high content of vitamins, phenols, and carotenoids [5-7].

Powdered fruit products may be an alternative to increase fruit consumption in response to the increased demand for ready-to-eat foodstuffs. The benefits of handling, packing, and transport of the fruit powder are the product's high stability and the ease of its final consumption. Powdered fruit products are sugar–rich foods, thus present structural problems like stickiness, caking, and collapse [8]. One way to prevent this is the addition of biopolymers of high-molecular-weight [9]. Biopolymers, such as gums, maltodextrins, proteins, starches, and natural fibre have been used as drying carriers to obtain stable powder fruits products [10-13]. However, the addition of biopolymers may cause effects in other properties, such as changes in porosity, colour, or microstructure of the final product [14].

Resistant maltodextrin (RMD), derived from heat treatment of corn starch, is a water-soluble fermentable functional fibre. Other authors have shown its important benefits such as being a satiating prebiotic [15, 16], reducer of glucose and triglycerides in the blood [17, 18], and promoter of good gut health [19]. Despite its functionality, there is still a need for further investigations on its use as a food formulation ingredient and their physicochemical property changes.

Spray drying (SD) is a well-established and widely used method for transforming liquid food products into powder form. The process of SD comprises transforming a product from fluid to a solid powdered state, through the dispersion of the product droplets inside a chamber where it contacts hot air [20]. Spray dried powders are more economical to produce than other processes, such as freeze drying [21]. SD has many applications, particularly in the food, pharmaceutical, and agrochemical industries [22–25]. However, drying fruit pulps or juices, such as sugar–rich foods, using SD is difficult as sticky products are produced, causing high operational costs and low product yield. To complete the process economically and with technical viability, it is necessary to add carrying agents [13, 26].

This study aimed to evaluate the effect of RMD addition on the physicochemical and structural properties of spray dried orange juice powders. Thus, to help promote fruit consumption in a useful format, with functional fibre.

2. Materials and Methods

2.1. Raw material

This study was conducted with freshly squeezed orange juice supplied by Refresco Iberia S.A.U. (València, Spain). Resistant maltodextrin (RMD; Fibersol-2) was purchased from ADM/Matsutani, LLC (Decatur, IL, USA).

2.2. Preparation of the feed mixture and spray drying (SD) conditions

Freshly squeezed orange juice was mixed with RMD, reaching RMD (2.5, 5, and 7.5%). The mixture was stirred for 30 min until homogeneous. After, the ºBrix was measured with a refractometer at 20 °C (PAL-BX/RI, Atago, Japan), it was fed into a Büchi B-290 (Switzerland) mini spray dryer with the following operating conditions: aspirator rate 90% (35 m^3/h); atomisation air rotameter 40 mm (473 L/h) with a co-current flow; pump rate 30% (9 mL/min), drying air inlet temperature was 150 °C, and the outlet temperature was registered. After the experiment was completed and when the air inlet temperature fell below 50 °C, the samples were collected from the product collection vessel.

For comparing physicochemical properties of spray dried samples to juice powder without RMD, freshly squeezed orange juice was freeze dried. A juice layer (0.5 cm thick) was placed on a standardised aluminium plate (15 cm diameter and 5 cm height) and frozen at -45 °C for 24 h, After, the sample was dried in a Lioalfa-6 Lyophiliser (Telstar, Spain) at 2,600 Pa at -56.6 °C for 48 h. This sample was the control.

2.3. Product yield, drying ratio, and productivity

Product yield (Yp) was defined as the ratio of the mass of solutes present in the powder obtained at the end of each SD period, to the mass of solutes present in the mixture prior to SD [27]. The SD drying ratio and productivity were calculated according to Cai and Corke [28] with slight modification. The drying ratio was calculated using equation (1) (powder solid content/feed solid content).

$$\text{Drying ratio} = \frac{(X_w^i + 1)}{(X_w^f + 1)} \quad (1)$$

Where X_w^i is the mixture feed moisture (dry basis) and X_w^f is the powder moisture (dry basis). The productivity was calculated using equation (2).

$$\text{Productivity (g/h)} = \frac{\text{Feed rate (g/h)}}{\text{Drying ratio}} \quad (2)$$

2.4. Physicochemical analysis

All the analyses on samples, described in this section, were conducted in triplicate.

2.4.1. Water content

The water mass fractions (g/100g) in freshly squeezed orange juice, mixtures with RMD, and obtained powders were obtained by vacuum drying the samples in a vacuum oven (Vaciotem, J.P. Selecta, Spain) at 70 ± 1 °C under a pressure of < 100 mmHg until achieving constant weight (AOAC, 2000).

2.4.2. Soluble solid content

The soluble solid mass fractions in freshly squeezed orange juice and mixtures with RMD (x_s) were determined by measuring the °Brix in a previously homogenised sample with a portable digital refractometer PAL-BX/RI, at 20 °C (Atago, Japan).

2.4.3. Hygroscopicity

To measure hygroscopicity [28], samples (about 1 g in a Petri dish) of each powder were placed at 25 °C in an airtight plastic container containing a Na2SO4 saturated solution (81% RH) at the bottom. After 1, 3, and 7 days, each sample was weighed and hygroscopicity was expressed as g of water gained per 100 g dry solids.

2.4.4. Bulk density and porosity

156 The porosity (ε), percentage of air volume related to the total volume, was calculated
157 from the true (ρ) and bulk (ρ_b) densities according to equation 3.

$$\varepsilon = \frac{(\rho - \rho_b)}{\rho} \quad (3)$$

158 The true density of powders was determined using a helium pycnometer (AccPyc 1330,
159 Micromeritics, Norcross, USA) and the bulk density by the ratio mass to volume of the
160 tapped samples according Agudelo et al. [10].

161

162 2.4.5. Water solubility index (WSI) and water absorption index (WAI)

163 The WSI and WAI were determined using the method of Singh and Smith [30]. A 2.5 g
164 sample was dispersed in 25 g of distilled water, using a rod to manually break up any
165 lumps. After stirring for 30 min using a magnetic stirrer, the dispersions were rinsed in
166 to tared 50 mL centrifuge tubes, made up to 32.5 g and centrifuged at 3,000 g for 10
167 min. The supernatant was decanted for determination of its dissolved solid content and
168 the sediment was weighed. WSI and WAI were calculated according to equations 4 and
169 5, respectively.

$$\text{WSI (\%)} = \left(\frac{\text{weight of dissolved solids in supernatant}}{\text{weight of dry solids}}\right) \text{x } 100 \quad (4)$$

170

$$\text{WAI} = \frac{\text{weight of sediment}}{\text{weight of dry solids}} \quad (5)$$

171

172 2.4.6. Colour measurement

173 The colour of the powder samples was measured using a Konica Minolta CM-700d
174 colorimeter (Konica Minolta CM-700d/600d series, Tokyo, Japan) with standard D65

175 illuminate and 10° visual angle. The powder was placed in a circular aluminium
176 sample holder of 17.7 mm in diameter and 9.53 mm in height. A reflectance glass (CR-
177 A51, Minolta Camera, Japan) was placed between the sample and colorimeter lens. The
178 measurement window was 6 mm in diameter. The results were expressed using
179 CIELab system [31]. Chroma; C* (saturation), hue angle; h*, and the total colour
180 difference (ΔE) taken orange juice freeze dried powder without RMD as reference were
181 also calculated.
182

183 *2.5. Powder morphology*

184 Morphology and surface microstructures of control and spray dried orange juice
185 powder with different RMD concentrations were examined using a Zeiss Ultra55 Field
186 Emission Scanning Electron Microscope (FESEM; Carl Zeiss AG, Germany) with the
187 Secondary Electron Detector (ETSE). The powder was fixed on a carbon adhesive tape
188 and was platinum coated before analysis. Images were taken at an accelerating voltage
189 of 1 kV and WD 3.5 mm. To examine the microstructure of samples, the electron mode
190 was used under ×100 magnifications; to avoid charging a sample micrograph was
191 taken after platinum coating. Three representative location areas were imaged for each
192 sample, and at least 12 images at different magnifications were obtained to assure the
193 FESEM imaging results were representative.
194

195 *2.6. Statistical analysis*

196 Analysis of variance (ANOVA), with a confidence level of 95% (p < 0.05), using
197 Statgraphics (Centurion XVII Software, version 17.2.04) was applied to evaluate the

differences among samples. A correlation analysis among all parameters studied, with a 95% significance level, was achieved (Centurion XVII Software, version 17.2.04).

3. Results and Discussion

Freshly squeezed orange juice presented a soluble solid mass fraction mean value (and standard deviation) 0.130 (0.002) $g_{soluble\ solid}/g_{product}$. After mixing with 2.5, 5, and 7.5% resistant maltodextrin (RMD) this changed to 0.153 (0.002), 0.172 (0.003), and 0.198 (0.002) $g_{soluble\ solid}/g_{product}$, respectively.

3.1. Spray drying (SD) parameters

Orange juice contains sugars and organic acids [32] which make the SD process difficult, mainly due to the basic physical characteristics of the low molecular weight sugars. Moreover, organic acids, such as tartaric, malic, and citric acid, also contributes to the problem of stickiness in the powder [22]. Therefore, it is extremely difficult to obtain powder at the exit of the dryer in samples without adding high-molecular-weight solutes, thus large deposits are formed on the main chamber and cyclone walls of spray driers.

Table 1 shows mean values and standard deviation of outlet temperature, product yield, drying ratio, productivity, and water content of spray dried samples with 2.5, 5, and 7.5% RMD. As seen, higher RMD concentrations give higher outlet temperatures and using different RMD % affected the outlet temperature significantly ($p < 0.05$). Further, the sample product yield increased with RMD %, however, the differences among samples are not significant ($p > 0.05$). The drying ratio decreased significantly

($p < 0.05$) when the RMD % increased, whereas the productivity increased significantly ($p < 0.05$) when RMD % increased. Several authors have reported that an increase in the maltodextrin content results in an increase of the recovery of feed solids in the product [10, 33, 34]. Water content of orange juice powder exhibited an inverse relationship with increasing RMD %, which was also reported by other authors working with maltodextrins or gum arabic [20, 25, 28, 35].

3.2. Physicochemical properties of obtained powders.

Water content, hygroscopicity, bulk density, porosity, water solubility, water absorption, colour, and structure of powders are important physicochemical properties to evaluate the suitability of orange juices powders.

Food powders with lower hygroscopicity and water content are considered good powdered products. Goula and Adamopoulos [35] suggested that adding maltodextrin decreased powder hygroscopicity. Figure 1 shows the evolution of hygroscopicity of each orange juice powder along the assay time. All samples increased their hygroscopicity gradually during the assay time. After 7 d, hygroscopicity of orange juice powder was significantly ($p < 0.05$) lower than the other samples when the RMD concentration was 5 or 7.5%. The lower hygroscopicity of orange juice powders when the RMD was added could be related to the less hygroscopic nature of maltodextrin. Other authors have reported similar observations [20, 25, 28, 35].

Figure 2 shows the bulk density and porosity of each orange juice powder. Comparing with the control, orange juice powders with 2.5 or 5% RMD were more similar than sample powder with 7.5% RMD. There was a significant ($p < 0.05$) increase of porosity and decrease of bulk density due to RMD concentration in powders. Porosity plays an important role in the agglomerate strength of dried foods [36]. Furthermore, a greater porosity (and lower bulk density) corresponds to a freer flowing powder with a greater air volume distributed among particles plus is more soluble [36, 37]. Other studies showed a similar trend as porosity increases when solutes with high-molecular-weight were added [10, 11].

Figure 3 shows the water absorption index (WAI) and water solubility index (WSI) of each orange juice powder. The WAI indicates the amount of water immobilised by the samples [38], whereas the WSI is related to the amount of soluble solids present in the product as a function of the solubilisation of starches, sugars, proteins, fibres, and maltodextrin [39]. Observed in Figure 3, the highest difference was between the control and spray dried samples, since the different processes (freeze and spray dried) affected the indexes significantly ($p < 0.05$). Besides, WAI and WSI of the orange juice powders were satisfactory because most of the solid elements in the powder obtained under the experimental conditions were easily soluble in water. The spray dried sample's WAI decreased significantly ($p < 0.05$) when higher RMD % was used. However, WSI did not show significant differences ($p > 0.05$) when adding RMD. Furthermore, spray dried samples presented higher WSI than the control (freeze dried sample).

Table 2 shows Pearson correlation coefficients among the x_w, WAI, WSI, ρ_b, ε and Hg_{7d} of orange juice spray dried powders. There were positive and significant ($p < 0.05$) correlations between x_w, WAI, and ρ_b. However, there was negative and significant ($p < 0.05$) correlation between x_w and ε Samples with higher water content presented higher amounts of water immobilised and bulk density and lower free flowing powders. Likewise, WAI showed significant positive and negative correlations ($p < 0.05$) with ρ_b and ε respectively. Further, powders with higher WAI are prone to agglomeration.

Colour coordinates of samples are shown in Table 3. The control showed L* and b* was like the spray dried sample with 2.5% RMD, however, a* was nearer to the spray dried sample with 5% RMD, while C* and h* were nearer with 7.5% RMD. Table 3 shows there was a significant ($p < 0.05$) effect of on colour coordinates with RMD addition. Colour of spray dried samples with RMD showed significant differences among studied % (2.5, 5 and 7.5). Powder with 2.5 % RMD presented the lowest L* and the highest a* and b*. When RMD concentration increased in spray dried samples, L* and h* increased while a*, b*, and C* decreased. This trend was also observed in other studies in grapefruit powders with gum arabic [10, 11]. Total colour differences between spray dried samples, and the control were higher than 3 units. Therefore, they are perceptible by human eye, which only distinguishes colour difference if ΔE^* is larger than 3 [40]. Total colour differences were higher when RMD concentration increased. Furthermore, there were significant ($p < 0.05$) differences among spray dried samples. The highest colour differences were observed in powders with 7.5 % RMD.

Figure 4 shows the appearance of the studied samples. In concordance with colour coordinates, orange juice spray dried with 7.5% RMD was more whitish. Powders with 2.5 % RMD was redder than the rest, as can be observed in Table 3 (a* colour coordinate). The control's appearance was like the orange juice spray dried with 2.5 or 5% RMD. Therefore, all samples could be suitable in relation with colour and appearance of powders.

Figure 5 shows FESEM micrographs of control and spray dried orange juice powders with 2.5, 5, and 7.5% RMD. Spray dried orange powder has a spherical or oval shape and smooth surfaced particles, typical of SD samples as shown by other authors in mangos [41] and lychees [42]. Powdered particles presented a continuous wall and the absence of surface cracks. Furthermore, when increasing RMD % in orange juice, powdered particles are smaller with a higher particle density, observed in the analysed field. This is likely related to more free flowing powders, because samples with 7.5% RMD were more porous (Figure 2). Moreover, in a concordance to Bazaria and Kumar [43], increasing the solids content in the liquid to be spray dried leads to a smoother particle surface. The average particle size obtained from micrographs of the powders was between 48 to 117 ⊚m. Particle size mean values (and standard deviation) of the control was 98 (3) μm; whereas spray dried samples were 117 (9), 77 (9), and 48 (8) μm for 2.5, 5, and 7.5% RMD, respectively. Therefore, the effect of RMD % on particle size is clear in spray dried samples; where an increase in % RMD provoked smaller particles size. These results are consistent with the findings of Tze et al. [44], studying maltodextrin % in spray dried pitaya fruit powders.

3. Conclusions

Resistant maltodextrin (RMD) added in orange juice to give powders by spray drying improved the productivity of the drying process. When RMD concentration increased in powders porosity and luminosity increased where the water content, bulk density, water absorption index, hygroscopicity, particle size, and redness decreased. Thus, samples with RMD were more porous and less hygroscopic, and presented low water content. These physicochemical properties are desirable for powders. However, high % RMD (7.5) showed high value of total colour differences. Therefore, to reach a compromise between the functionality of the powders indicated by other authors and the possible changes of their physicochemical properties, especially colour, the addition of 5% RMD is recommended. Consequently, the adequate physicochemical properties of the powdered product obtained from orange juice are maintained to a greater extent.

Acknowledgements:

The authors thank Refresco Iberia S.A.U. for supplying the freshly squeezed orange juice.

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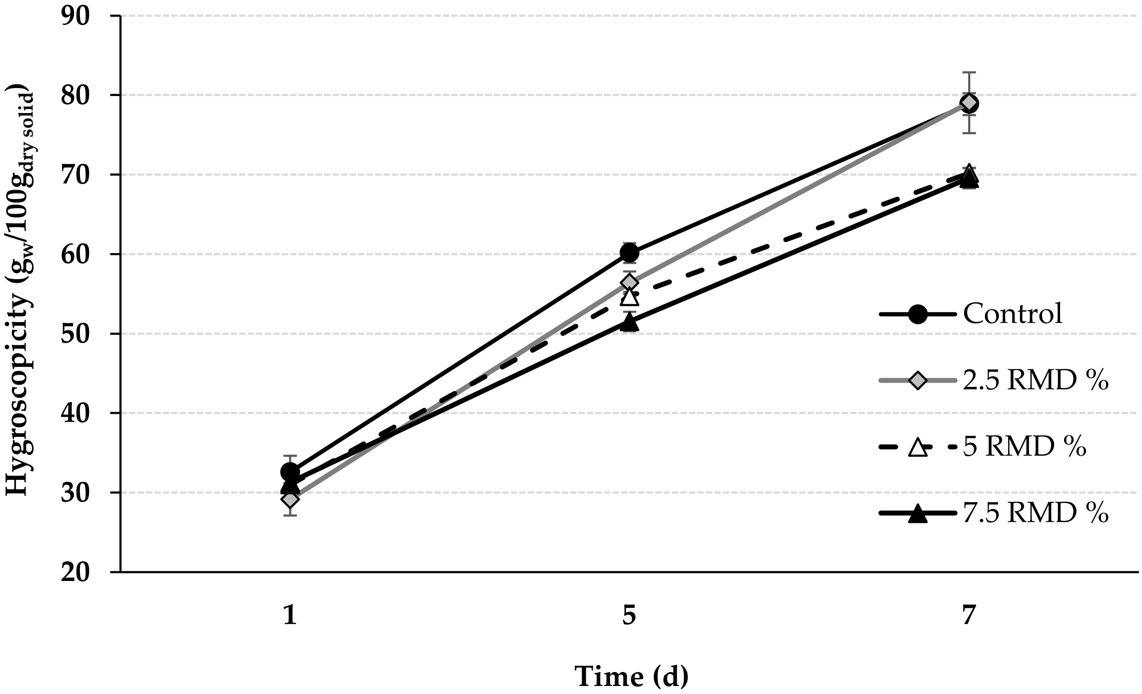
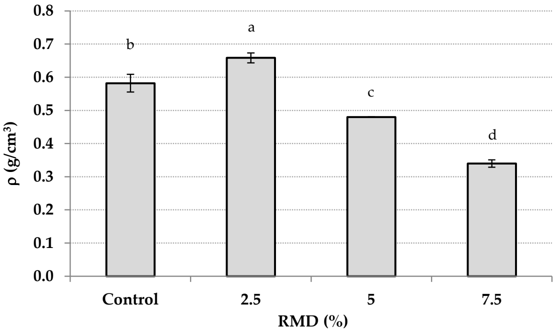
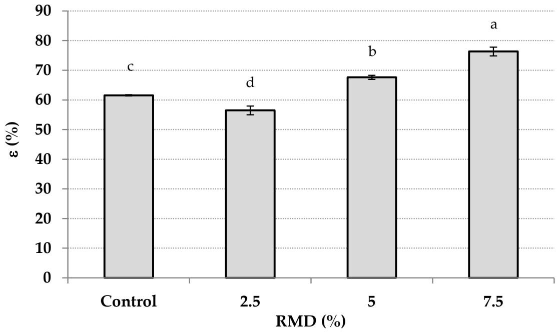


Figure 1. Evolution of hygroscopicity (mean and standard deviation) of each orange juice powder along the assay time.



(a)



(b)

Figure 2. Mean values and standard deviation of (a) bulk density and (b) porosity. Letters indicate homogeneous groups established using the ANOVA ($p < 0.05$) for each parameter analysed.

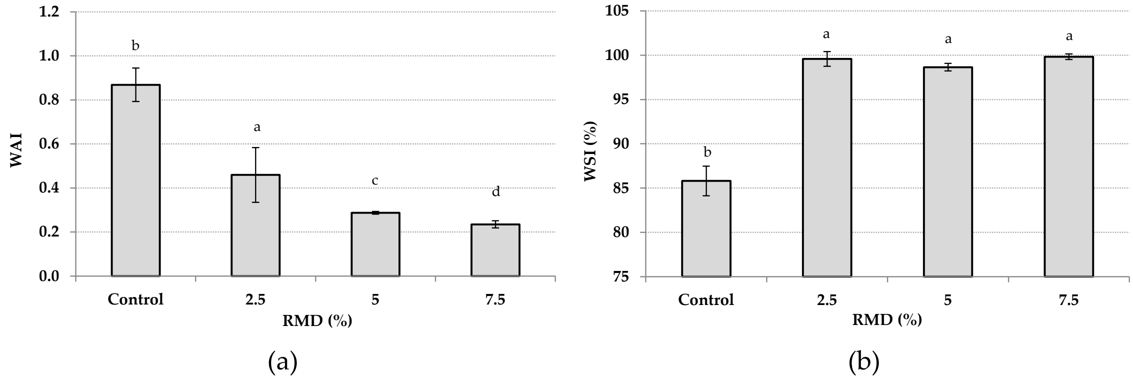


Figure 3. Mean values and standard deviation of (a) water absorption index and (b) water solubility index. Letters indicate homogeneous groups established by the ANOVA ($p < 0.05$) for each parameter analysed.

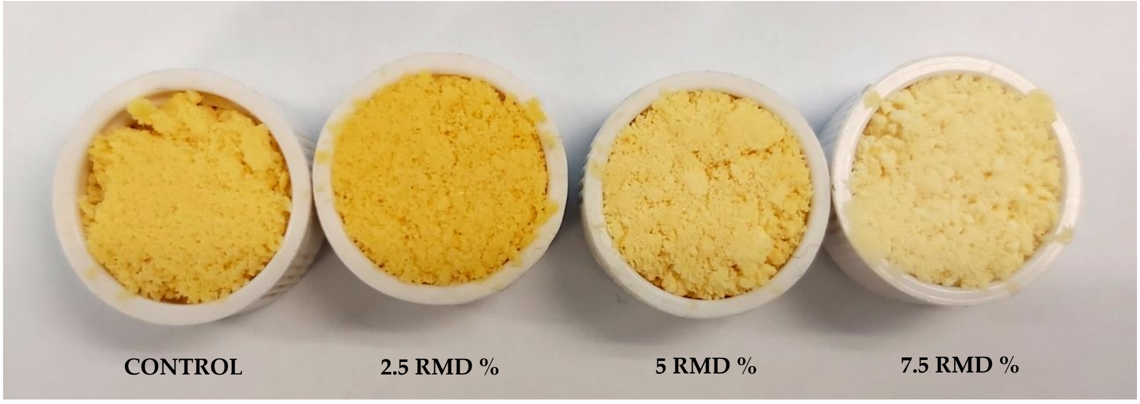


Figure 4. Appearance of studied orange juice powder samples.

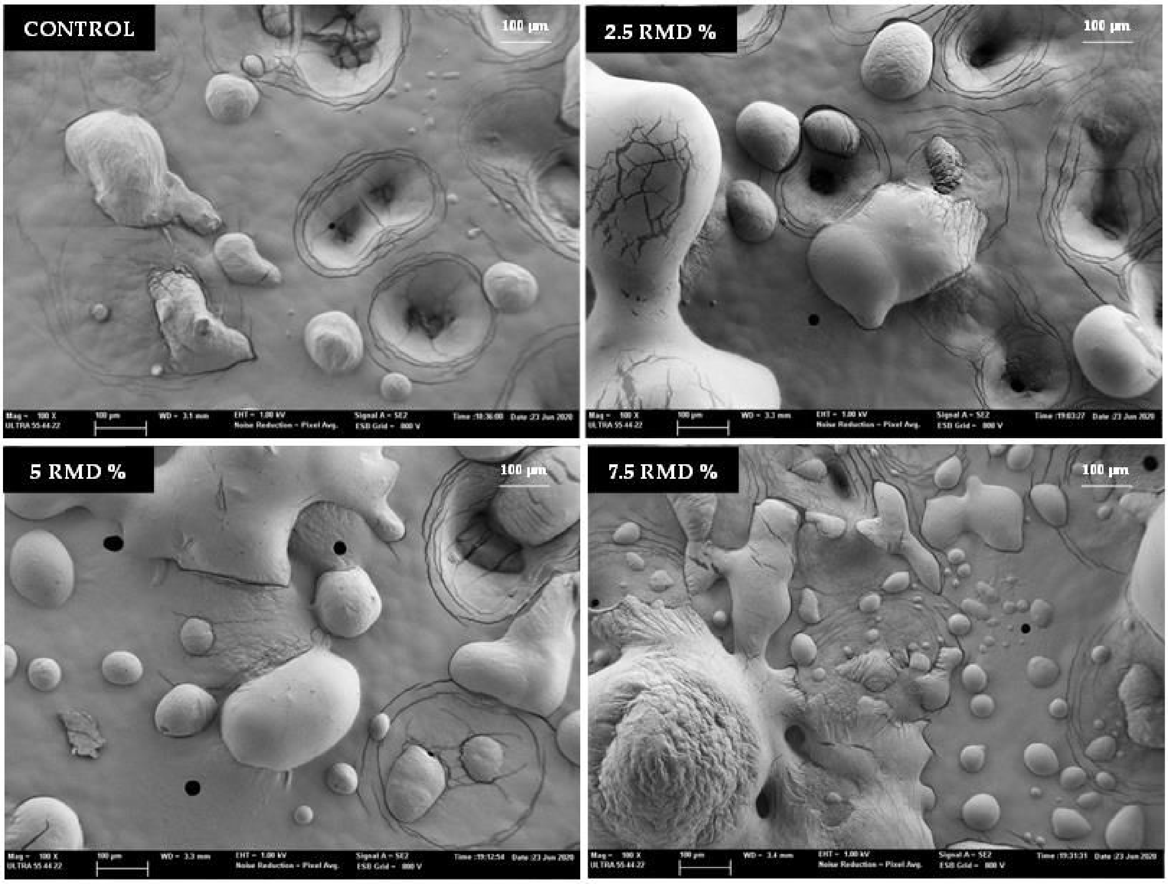


Figure 5. FESEM micrographs at 100 magnifications of studied samples.

Table 1. Outlet temperature, product yield, drying ratio, productivity, and water content (x_w) mean values (and standard deviation) of spray dried powers.

Parameter	**% of RMD**		
	2.5	**5**	**7.5**
Outlet temperature (°C)	86.5 (1.2)^{c}	91.0 (0.6)^{b}	94.3 (0.8)^{a}
Product yield ($g_{solutes\ in\ the\ powder}$/100 $g_{solutes\ in\ the\ mixture}$)	44.0 (0.3)^{a}	44.8 (0.6)^{a}	44.9 (0.2)^{a}
Drying ratio	5.935 (0.015)^{a}	5.363 (0.012)^{b}	4.895 (0.003)^{c}
Productivity (g/h)	99.86 (0.06)^{c}	114.80 (0.09)^{b}	126.9 (0.5)^{a}
x_w (g_{water}/$g_{product}$)	0.0952 (0.0003)^{a}	0.0751 (0.0012)^{b}	0.0512 (0.0012)^{c}

Letters indicate homogeneous groups established by the ANOVA ($p < 0.05$) within rows.

Table 2. Pearson correlation coefficients among studied parameters of orange juice powders.

	WAI	WSI	ρ_b	ε	Hg_{7d}
x_w	0.8341*	-0.2006	0.9907*	-0.9828*	-0.7634
WAI		-0.1587	0.8377*	-0.8844*	0.5662
WSI			-0.0700	0.1453	0.4626
ρ_b				-0.9863*	0.8370*
ε					-0.7665

* Correlation is significant at the 0.05 level.

Table 3. Mean values (and standard deviations) of colour coordinates (L*, a*, b*, C*, and h*) and total colour differences (ΔE) of orange juice powders.

	Control	2.5% RMD	5% RMD	7.5% RMD
L*	79.9 (0.8)^{c}	78.4 (0.7)^{d}	83.0 (0.6)^{b}	87.1 (0.4)^{a}
a*	4.40 (0.13)^{b}	6.8 (0.4)^{a}	3.7 (0.3)^{c}	1.113 (0.108)^{d}
b*	45.7 (0.2)^{b}	50.9 (0.7)^{a}	40.5 (0.5)^{c}	31.7 (0.6)^{d}
C*	21.7 (1.4)^{d}	51.3 (0.8)^{a}	40.7 (0.5)^{b}	31.7 (0.6)^{c}
h*	87.5 (0.8)^{a}	82.4 (0.4)^{c}	84.8 (0.4)^{b}	88.0 (0.2)^{a}
ΔE		5.8 (0.9)^{b}	6.3 (0.7)^{b}	16.3 (0.7)^{a}

The same letter in superscript within row indicates homogeneous groups established by ANOVA ($p < 0.05$).