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Screening efficiency and rolling effects of a rotating screen drum used to process wet soft agglomerates

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1                   **Screening efficiency and rolling effects of a rotating screen drum**  
2                   **used to process wet soft agglomerates**

3  
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11  
12  
13 **Abstract** - The rotating screen drums are largely used in most powder handling and  
14 processing industries. They are commonly used for size separation of granular materials.  
15 Objectives of the present work are to better understand both roles, screening efficiency and  
16 shaping effects and to investigate and model which process parameters are relevant when  
17 using an inclined rotating screen drum for processing wet couscous agglomerates. Durum  
18 wheat semolina was used as raw material to produce the wet agglomerates. The pilot rotating  
19 screen drum equipment was composed of two sieves to separate three fractions: fine, medium,  
20 and large agglomerates. The shaping effects of the rotating screen drum were evaluated from  
21 the measurements of the physico-chemical characteristics (size distribution, water content,  
22 compactness, and circularity) on wet soft agglomerates. To describe the screening efficiency  
23 parameters of a rotary screen drum, a specific method was developed by using a matrix  
24 analysis of the different measured weights of the collected products. The impacts of rotating  
25 screen drum parameters (angle of inclination, rotating speed, and product flow rate) on the  
26 sieving efficiency and on the shaping effects were investigated. The present results  
27 demonstrate high apparent screening efficiency of the rotating screen drum when used with  
28 wet agglomerates of durum wheat, ranging between 89 and 96% depending on the process  
29 conditions. Finally, using dimensional analysis, two correlations were proposed on the  
30 circularity and the apparent screening efficiency whatever the operating conditions used  
31 (drum speed, angle of inclination and feed rate).

32  
33 **Keywords** - Rotating screen drum, durum wheat couscous, circularity, agglomeration  
34 mechanisms, dimensional analysis.

## 35 1. Introduction

36

37 The rotating drums are equipments largely encountered in process lines (both in continuous  
38 and batch modes) for handling and processing power and wet media. Indeed simple cylinders  
39 rotating about their central axis can be used in a horizontal position as batch drums, or as  
40 continuous drums when inclined at a few degrees to generate granular flows. The rotating  
41 drums are very versatile by realizing a large diversity of unit operations (e.g. solid-solid  
42 separation, mixing, drying, heating, chemical reactions, spraying, coating, granulation,  
43 screening, shape classification, etc.) in a large number of fields of application (e.g.  
44 environmental, chemical, mineral, metallurgical, food, pharmaceutical and civil engineering  
45 sectors, etc.). Different regimes for granular flow in rotating drums can occur (slipping,  
46 slumping, rolling, cascading, cataracting, and centrifuging modes) as a function of the process  
47 conditions, the regime type impacting on the process efficiency (Ding et al., 2001; Gray et al.  
48 2001; Mellman, 2001; Spurling et al. 2001; Ding et al., 2002; Scott et al. 2009; Liu and  
49 Specht, 2010; Liu et al. 2013; Komosa et al. 2014).

50 Among the applications, the rotating screen drums are commonly used for size separation of  
51 granular materials. The rotating screen drums are relatively simple, low expensive, requiring  
52 little operating and maintenance costs compared to other separation systems. It consisted of a  
53 cylindrical perforated drum that rotated to perform size separation. Perforations or holes in the  
54 cylinder allow smaller materials to drop out during the rotation process. The fine particles are  
55 then first separated, at the beginning of the screening process. Due to the inclination of the  
56 drum, the remaining particles travel onward to the subsequent screening rings to be separated.  
57 Over-sized materials pass through the rotating screen drum. The flow of particles through the  
58 orifices on the rotating drum occurs due to the combination of the mobility of grains (like  
59 falling in avalanches, ballistic trajectory...) caused by the rotation regime of the drum and  
60 jamming in the vicinity of the orifices. The rotating screen drum can be managed by  
61 controlling the product flow, the driving speed and inclination angle of rotation axis (Prasanna  
62 Kumar, 2005; Chen et al 2010; Koprál et al., 2011). The screening efficiency was inversely  
63 proportional with the product flow rate and the drum rotational speed. An increase of the  
64 angle of inclination of the drum improves the screening efficiency, until a critical angle that  
65 generates too high horizontal motion velocity of the particles on the drum screen. The rotating  
66 screen drum can also classify particles of different shapes with different residence times of  
67 particles in the drum due to the particle shape (Furuuchi et al., 1993; Hartmann et al., 2006).

68 Attempts to predict performance of rotating screen drums still remain unsatisfactory due to a  
69 lack of understanding of the screening mechanisms when applied to continuous screening.  
70 Prasanna Kumar (2005) studied the effect of the various screen drum, grain and operating  
71 parameters on the flow rate of grains and developed empirical equations for the flow rate by  
72 dimensional analysis. The spacing between orifices, the diameter of orifice, the percent fill of  
73 drum and rotational speed of the drum significantly affect the screening flow rate.  
74 Comprehensive effect of granular flow under various operational parameters and screening  
75 methods are not yet been thoroughly understood, more particularly if the granular materials  
76 are characterized by heterogeneous size distribution (Liu, 2009; Chen et al., 2010). Some  
77 works have developed modelling by the dimensional analysis approach and proposed  
78 integrated models considering the equipment characteristics and the process conditions  
79 (Bongo Njeng, 2016, Prasanna Kumar, 2005).

80 The granular flow inside rotating drums may generate undesirable breakage or erosion of the  
81 granular material. These mechanisms were observed inside a rotary drum, due to impacts and  
82 wear with the drum walls and shear deformation within the granular material (Grant and  
83 Klamann, 2001, Ahmadian et al., 2011). The breakage trends of the grains were found to  
84 increase with rotational speed. Inside a rotary drum, granular material may experience  
85 impacts and wear with the drum walls and shear deformation within the powder bed.  
86 Knowledge of the powder dynamics remains essential to understand how particulate material  
87 breaks inside a drum.

88  
89 In the food domain, the rotating drum screens are used for the manufacturing of the classical  
90 couscous grains. The couscous grains are made with durum wheat semolina, by the  
91 succession of four unit operations: wet agglomeration, rolling-sieving, steam cooking, and  
92 drying (Abecassis et al., 2012; Ruiz et al., 2014). At the end of the wet agglomeration stage,  
93 the soft wet agglomerates made of durum wheat semolina and water are continuously  
94 introduced inside an inclined rotating screen drum, constituted by successive screens of  
95 increasing meshes. This equipment is known to play two roles in the process of couscous  
96 grains. First the screening role, by separating the wet agglomerates according to their size, in  
97 order to only select those in the expected range of diameters (between 1 and 2 mm). It also  
98 contributes to the couscous grain structure, by modifying the shape and the density of the wet  
99 agglomerates due to the mechanical stresses that are promoted by granular flow inside the  
100 rotating drum. It is the rolling effects. The grains of couscous rolled in the rotary drum are  
101 more spherical and less porous, than those that are sieved on traditional horizontal vibrating

102 sieves (Hébrard, 2002; Abecassis et al., 2012). However, no scientific works have described  
103 the secondary agglomeration mechanisms that could occur on soft plastic grains during their  
104 flow inside a rotating drum. It should be noticed that on the current industrial lines, the  
105 rotating drum screens still generate large flow rates of under- and over-sized grains, after the  
106 wet agglomeration stage. These flows rates can represent more than 2.5 times the flow rate of  
107 target product. No study on the rolling stage during the process of the couscous grain has been  
108 yet conducted.

109 The objective of the present work is to develop an approach to better understand the two roles  
110 (screening efficiency and shaping effects) of the inclined rotating screen drum when used with  
111 the soft wet couscous agglomerates. Durum wheat semolina was used as raw materials to  
112 produce the wet agglomerates. The pilot rotating screen drum equipment was composed of  
113 two sieves to separate three fractions: fine, medium, and large agglomerates. The shaping  
114 effects of the rotating screen drum were evaluated from the measurements of the physico-  
115 chemical characteristics (size distribution, water content, compactness, and circularity) of the  
116 wet agglomerates, before and after processing by the rotating drum. The impacts of rotating  
117 screen drum parameters (angle of inclination, rotating speed, and product flow rate) on the  
118 sieving efficiency and on the shaping effects were investigated. A dimensional analysis  
119 approach is proposed to establish some relationships between the characteristics of the  
120 agglomerates and the process parameters. Experimental results give the very first tendency of  
121 this correlation.

122  
123

## 124 **2. Materials and methods**

125

### 126 *2.1. Raw materials*

127 Durum wheat semolina of industrial quality (Panzani group, France) was used as raw material  
128 for the agglomeration experiments. Semolina was stored in hermetic containers at 4°C until  
129 experiments were carried out (less than 6 months). Semolina was first characterized using  
130 standardized methods. The water content of semolina ( $16.0 \pm 0.5$  g water / 100 g dry  
131 semolina) was determined according to the approved method 44-15A (AACC, 2000), by  
132 weighing after oven drying (RB 360, WC Heraeus GmbH, Hanau, Germany) at 105°C for 24  
133 h. The characteristics values ( $d_{10} = 66 \pm 1 \mu\text{m}$ ;  $d_{50} = 283 \pm 1 \mu\text{m}$ ;  $d_{90} = 542 \pm 4 \mu\text{m}$ ) of particle  
134 diameter of semolina ( $d_{50} = 283 \pm 1 \mu\text{m}$ ) were measured by a laser granulometer (Coulter  
135 TMLS 230, Malvern, England) at room temperature. The diameter span ( $(d_{90}-d_{10})/d_{50}$ ) was

136 1.67. The semolina true density ( $1.478 \pm 0.005 \text{ g.cm}^{-3}$ ) was measured by azote pycnometry.  
137 The total nitrogen content (TN) of semolina was determined by the Kjeldahl method, and the  
138 crude protein content (12.3 g protein/100 g dry matter) was calculated according to TN - 5.7  
139 based on the AFNOR method V 03-050 (AFNOR, 1970).

140

141

## 142 2.2. Agglomeration process

143 The wet agglomeration process was conducted by using a horizontal low shear mixer. A  
144 sample of 5.0 kg of semolina was first introduced in the mixing tank (48.5 cm length, 20.0 cm  
145 width, and 19.0 cm height). The two horizontal shaft axes were positioned at 6.1 cm from the  
146 bottom of the tank, with 12 metal rotating paddle blades (47.5 cm length and 14.0 cm gap  
147 between 2 blades). The sample of semolina was mixed for 2 min at constant mixer arm speed  
148 (80 rpm) to equilibrate the temperature at  $25^\circ\text{C} (\pm 2^\circ\text{C})$ . Water was directly poured over the  
149 semolina under mixing at almost constant flow rate ( $8 \text{ g.sec}^{-1}$ ) during 2 minutes. Water  
150 addition was conducted to reach a final water content of 42.5 g water/100 g dry matter. After  
151 the water addition step, the mixture was stirred for 18 min to homogenize and agglomerate.  
152 The wet agglomerates were then collected using a plastic bowl and directly introduced in the  
153 rotating drum equipment.

154

155

## 156 2.3. Rolling processes

157 Experiments were performed in the rotating screen drum as illustrated in Fig. 1. It consisted  
158 of a cylindrical stainless-steel screening device (0.5 m diameter and 1 m total length) that  
159 rotated to perform rolling and size separation of the agglomerates. The cylinder was supported  
160 by a central axis and rotated by an electric motor and belt drive. The rotating screen drum  
161 consists of 2 successive joined cylindrical screening cylinders, each of 0.5 m height, having a  
162 0.44 mm effective screening length (screen area =  $69 \text{ cm}^2$ ). Sieve holes were round holes of 1  
163 and 2.2 mm diameter. The ranges of experimental conditions were determined in regards with  
164 the capacities of the experimental equipment and with the values classically used in the  
165 industry. Different inclinations ( $5.1, 6.2, 7.4, 9.7, \text{ and } 12.0^\circ$ ) and different angular rotating  
166 drum speeds:  $0.21, 0.79, 1.36, 2.09 \text{ and } 2.72 \text{ rad.s}^{-1}$ , which respectively correspond to: 2, 7.5,  
167 13, 20, and 26 rpm, of the drum were tested. The wet agglomerates were continuously fed by  
168 using a vibrating feeder inside the rotating drum, tangentially to the bottom of the first  
169 screening ring. Different feed rates ( $6.7, 11.4, 20.7, \text{ and } 25.3 \text{ g.sec}^{-1}$ ) were tested. Depending

170 on the operating conditions, the total time of the rolling/screening stage ranged between 10  
171 and 15 minutes.

172 The fine agglomerates are first collected in a drawer under the first screen (1 mm). The  
173 medium agglomerates are collected in a drawer under the second screen (2.2 mm). The large  
174 agglomerates are discharged out of the drum and collected in a third drawer. For each  
175 experiment, the mass of the collected agglomerates in the three drawers was weighed.

176

177

#### 178 *2.4. Screening efficiency parameters of the rotating screen drum*

179 To describe the screening efficiency parameters of a rotary screen drum, we have developed a  
180 specific method by using a matrix analysis of the different measured weights of the collected  
181 products. The method is based on the calculation of mass fractions (Fig. 2).

182

183 A mass ( $m^0$ ) of the initial agglomerates is introduced in the drum. The rotating screen drum  
184 separates the initial powder in different products. The rotating drum is equipped by a number  
185  $P$  of screens of increasing mesh. A number of  $P+1$  products ( $i$ ) is collected in the  $P+1$   
186 drawers. The mass ( $m_i$ ) of each  $i$  collected product was measured in each drawer. The total  
187 mass of the collected products ( $m$ ) is the sum of the masses ( $m_i$ ) of the  $i$  products collected in  
188 the drawers. We supposed no mass accumulation inside the rotating drum ( $m = m^0$ ).

189 We defined the mass fraction ( $x_i$ ) for the product  $i$ , by the ratio of its mass ( $m_i$ ) over the total  
190 mass ( $m$ ) of collected product:

$$191 \quad x_i = \frac{m_i}{m} \quad (1)$$

192

193 with:  $\sum_{i=1}^{P+1} x_i = 1$  and:  $m = \sum_{i=1}^{P+1} m_i$ . The initial powder and the collected products are  
194 characterized by their fractions, according to the standard sieving procedure using a column  
195 of a number of  $N$  sieves of decreasing mesh (Fig. 2). A number of  $N+1$  fractions ( $j$ ) is  
196 characterized using the  $N$  sieves. The masses ( $m_{ij}$ ) of each fraction  $j$  from each  $i$  product, are  
197 measured.

198

199 For the initial powder, we defined the mass fraction ( $x_j^0$ ), by the ratio of the mass of its  
200 fraction  $j$  ( $m_j^0$ ) over the total mass ( $m^0$ ) of the initial powder:

201

$$202 \quad x_j^0 = \frac{m_j^0}{m^0} \quad (2)$$

203

204 With:  $\sum_{j=1}^{N+1} x_j^0 = 1$  and:  $m^0 = \sum_{j=1}^{N+1} m_j^0$ . For each  $i$  collected product ( $\forall i \in \{1, \dots, P+1\}$ ),  
 205 we defined three mass fractions ( $x_{ij}$ ,  $y_{ij}$  and  $z_{ij}$ ), by the ratio of the mass of their fraction  $j$  ( $m_{ij}$ )  
 206 over the different total masses: total mass of the collected products ( $m$ ), total mass of the  
 207 collected product in the drawer  $i$  ( $m_i$ ), and total mass of the fraction  $j$  of all the collected  
 208 product ( $m_j$ ), respectively:

$$209 \quad x_{ij} = \frac{m_{ij}}{m} \quad (3)$$

$$210 \quad y_{ij} = \frac{m_{ij}}{m_i} \quad (4)$$

$$211 \quad z_{ij} = \frac{m_{ij}}{m_j} \quad (5)$$

212

213 with:  $\sum_{j=1}^{N+1} \sum_{i=1}^{P+1} x_{ij} = 1$ ,  $\sum_{i=1}^{P+1} x_{ij} = x_j$ ,  $\sum_{j=1}^{N+1} x_{ij} = x_i$  and  $m = \sum_{j=1}^{N+1} \sum_{i=1}^{P+1} m_{ij}$ . Also: (i)  
 214  $\forall j \in \{1, \dots, N+1\} \sum_{i=1}^{P+1} y_{ij} = 1$  and  $m_i = \sum_{i=1}^{P+1} m_{ij}$ , (ii)  $\forall i \in \{1, \dots, P+1\} \sum_{j=1}^{N+1} z_{ij} = 1$  and  
 215  $m_j = \sum_{j=1}^{N+1} m_{ij}$ . This specific method is used to describe the screening efficiency of the  
 216 rotating screen drum for wet agglomerates of durum wheat.

217

218

#### 219 2.4. Characterization of the agglomerates

220 Water content - The water content ( $w$ ) of agglomerates (dry base) was determined on 3-5 g  
 221 samples, by a drying method in an oven (RB 360, WC Heraeus GmbH, Hanau, Germany) at  
 222 105°C for 24 h (AACC Method 44-15A). Mean values were determined from triplicate:  
 223  $w = m_w/m_s$ , where  $w$  is the water content of agglomerates (g / g dry matter),  $m_w$  is the mass  
 224 of water (g) and  $m_s$  is the mass of dry matter (g) in the sample.

225

226 Size distribution - A specific method was proposed to measure the distribution according to  
 227 size criterion of the wet agglomerates. The size distribution was measured for the initial wet  
 228 agglomerates (before introducing them in the rotating screen drum) and for the three products,  
 229 that are collected after the rotating screen drum in the drawers. Size distribution was  
 230 determined by sieving a sample of 100 g on the top of a column of 2 sieves of decreasing  
 231 meshes (2 and 1 mm). The two sieves were chosen with almost similar meshes values,  
 232 compared to the meshes of the two screens (1 and 2.2 mm) of the rotating drum.

233 The sieve column was mechanically mildly shacked using a rotachoc equipment (Rotachoc,  
 234 Chopin Technologies, France) at 200 rpm for 5 min, to limit the particle breakage during the

235 mechanical shaking process (Saad et al., 2011). The possible broken effect is supposed similar  
236 for all the different products. The size distribution was obtained by weighing the mass of  
237 agglomerates on each sieve. The weight distribution according to size criteria was expressed  
238 as the percent of total weight. Measurements were conducted in triplicate.

239  
240 *Compactness* - Samples of agglomerates (about 1 g) were used to determine the compactness,  
241 *i.e.* the solid volume fraction:  $\phi = \rho_s / \rho_s^*$ , according to Rondet et al. (2009). The solid  
242 apparent density  $\rho_s$  of the wet agglomerates was measured by using a hydrostatic balance with  
243 paraffin oil, which ensures the wet agglomerates without penetrating them. The solid true  
244 density  $\rho_s^*$  was measured by using a nitrogen pycnometer (ULTRAPYC 1200e, Quatachrom)  
245 after drying the agglomerates at 105°C for 24h.

246  
247 *Agglomerates shape* - For each rolled product, we sampled a number of agglomerates  
248 (between 10 to 30) to be statistically representative of the shape of the sample. The selected  
249 wet agglomerates were dispersed on glass slides and observed by a camera (Lumix DMC-  
250 FS11, Panasonic, Tokyo, Japan). Image analyses were carried out with Fiji® software by  
251 following these steps:

- 252 - Image pre-treatment includes particle's border killing (removes particles that touch  
253 the border of the image), particle's silhouette hole filling (filling the holes within  
254 particle silhouette), separation function (breaks narrow isthmuses and separates  
255 touching particles), and morphological cleaning.
- 256 - Calibration step implies a translation from pixel unit into metric units.
- 257 - Measurements of the silhouette dimensions: Perimeter (P) and Area (A).
- 258 - The circularity shape factor is defined as the ratio of the perimeter of the silhouette  
259 (P) and the circumference of a disk that has the same area (A) as the silhouette. For a  
260 disk, circularity equals 1. Circularity value is lower than 1, when the projected shape  
261 of the particle departs from a disk, either because of a high roughness in particle  
262 surface or because of elongation. Circularity is equal to 0.89 for a square and to 0.50  
263 for a long rectangle:  $Circularity = P / 2\sqrt{\pi A}$ . The presented values of the circularity  
264 shape factors were mean of the measured values.

265

266

267 *2.5. Statistical analysis*

268 The statistical significance of results was assessed using single factor analysis of variance  
269 (ANOVA). Multiple comparisons were performed by calculating the least significant  
270 difference using Microsoft Excel 2010, at a 5% significance level.

271

272

### 273 3. Experimental results

274

#### 275 3.1. Shaping effects of the rotating screen drum

276 The characteristics of the wet agglomerates were determined immediately after the wet  
277 agglomeration stage, just before the introduction in the rotating drum (Table 1). The wet  
278 agglomerates are characterized by their water content (0.42), compactness (0.597), and weight  
279 distribution of the three fractions according to size criterion.

280 Physicochemical characteristics of the three fractions of the native agglomerates that were  
281 collected after the standardized method for the size distribution measurement were also  
282 measured (Table 1). It can be noticed the relatively low value of the mass fraction ( $x_2 =$   
283 0.285) for the medium initial agglomerates (between 1 and 2 mm). This low value is typical  
284 of the instantaneous agglomeration yield for the wet agglomeration operation, as usually  
285 observed during the industrial processing of the couscous grains (Abecassis et al., 2012).

286 It can be observed that the physicochemical characteristics of the wet agglomerates depend on  
287 their diameters. The large agglomerates are characterized by high water content (0.47) and  
288 low compactness (0.573). The small agglomerates are characterized by low water content  
289 (0.40) and high compactness (0.614). The dispersion of water content and compactness values  
290 according to the size of the agglomerates (Table 1) is typical of the growth mechanisms  
291 associated with the wet agglomeration process under low shear of wheat powders (Barkouti et  
292 al., 2012).

293 The shape description of the agglomerates was only conducted for the median fraction (1 mm  
294 < diameter < 2 mm), which is classically selected for the production of the couscous grains.  
295 The circularity value (0.636) typifies shape not totally spherical.

296

297 The present work has been conducted to investigate if the high water contents and the large  
298 dispersion of diameters measured for the wet agglomerates could favour (or not) the  
299 occurrence of specific mechanisms during the processing inside the rotating drum, with  
300 possible plastic strains under mechanical stresses, densification mechanisms under pressure,  
301 and potential difficulties in sieving mechanisms. Processing the initial wet agglomerates with

302 the rotating screen drum generates three rolled products by sieving mechanisms. The  
303 physicochemical characteristics of the three products have been determined (Table 2).  
304 Processing with the rotating screen drum slightly affects the characteristics of agglomerates.  
305 We observed slightly higher values of the water content for the agglomerates collected in the  
306 drawer 1 and drawer 2 after the rolling stage, when compared with the water content of the  
307 small and medium fraction in the initial wet agglomerates (Table 1). We could suppose that  
308 the rolling process induced erosion or breakage mechanisms of the large wet agglomerates  
309 that generated smaller agglomerates with high water content that are collected in the drawers  
310 1 and 2. On the other hand, we observed lower values of the water content for the  
311 agglomerates collected in the drawer 3 after the rolling stage (0.434), when compared with the  
312 water content of the large fraction in the initial wet agglomerates (0.473) (Table 1). We can  
313 consider two hypotheses. Drying mechanisms could occur during the rolling process and  
314 impact all the agglomerates. The experimental results allowed observing a slight reduction of  
315 the global water content of the large agglomerates. We did not observe a reduction of the  
316 water content of the medium and small agglomerates, because of the fragmentation  
317 mechanisms of the large wet agglomerates, which compensate the drying mechanisms. The  
318 granular flow inside the drum could also promote agglomeration mechanisms with the  
319 adhesion of initial small and large agglomerates.

320  
321 The rolling process does not impact the compactness values for the medium and large  
322 fractions of the agglomerates, as similar values were measured before and after the rolling  
323 process (Tables 1-2). We can suppose that the mechanical stresses generated by the shearing  
324 conditions of the granular flow inside the rotating drum is not enough sufficient to promote  
325 densification of the wet agglomerates of durum wheat. We measured slightly higher values of  
326 the compactness for the small fraction of agglomerates. This value is unusually high and  
327 could be partly explained by the method of the displaced volume in the paraffin oil, which is  
328 not well adapted to measure the solid volume fraction for the small agglomerates.

329 The shape characteristics of the rolled agglomerates were measured. The rolling process  
330 induces slightly higher values of circularity for the medium fraction (0.668), when compared  
331 with the initial wet agglomerates (0.636). We can suppose that the mechanical stresses  
332 generated by the rolling process could slightly impact the shape of the wet soft agglomerates  
333 through erosion or densification mechanisms and as a consequence increase their circularity.

334

335

336 *3.2. Screening efficiency of the rotating screen drum*

337 To describe the screening efficiency parameters of a rotary screen drum, we have developed a  
 338 specific method by using a matrix analysis of the different measured weights of the collected  
 339 products (Fig. 2). The mass fractions ( $x_{ij}$ ) of the different collected agglomerates are first  
 340 calculated over the total mass ( $m$ ) of collected products (Table 3). We define the apparent  
 341 screening efficiency of the rotating screen drum by considering the sum of the mass fractions  
 342 of the diagonal of the matrix ( $x_{11}+x_{22}+x_{33} = 0.923$ ), which indicates that 92.3% of the wet  
 343 agglomerates are collected in the right drawer according to their size.

344  
 345 We define the global process efficiency by taking into consideration the mass fraction of the  
 346 medium agglomerates ( $j=2$ ) collected in the second drawer ( $i=2$ ) ( $x_{22}=0.332$ ), which indicates  
 347 that 33.2% of medium agglomerates are produced by the agglomeration process and collected  
 348 in the right drawer.

349  
 350 We define the impact of the processing inside the rotating screen drum on the size distribution  
 351 of agglomerates, by calculating the relative difference of the mass fractions of the three  
 352 classes of agglomerates ( $j$ ) before and after processing ( $100 (x_j - x_j^0) / x_j^0$ ). The present results  
 353 (Tables 1-3) demonstrate a decrease of the mass fraction of the small agglomerates  $j=1$  (-  
 354 13.7%) and an increase of the mass fraction of the medium agglomerates  $j=2$  (+26.0%). On  
 355 the other hand, the processing inside the rotating screen drum does not affect the mass  
 356 fraction of the large agglomerates  $j=3$  (-3.9%)

357  
 358 We calculated the mass fractions ( $y_{ij}$ ) of the different collected agglomerates, over the total  
 359 mass ( $m_i$ ) from the collected products in the drawer  $i$  (Table 4). We define the contamination  
 360 rate of the collected product targets by taking into consideration the mass fraction of the small  
 361 agglomerates ( $j=1$ ) collected in the second drawer ( $i=2$ ) ( $y_{21}=0.115$ ), which indicates that  
 362 11.5% of products collected in the second drawer are too small in regards with the  
 363 specifications.

364  
 365 We calculated the mass fractions ( $z_{ij}$ ) of the different collected agglomerates, over the total  
 366 mass ( $m_j$ ) of the fraction  $j$  from all the collected products (Table 5). We define the loss rate of  
 367 the targeted product by taking into consideration the mass fraction of the medium  
 368 agglomerates ( $j=2$ ) collected in the third drawer ( $i=3$ ) ( $z_{32}=0.074$ ), which indicates that 7.4%  
 369 of the medium agglomerates are not collected in the right second drawer.

370

371 This original approach using matrix analysis has never been completed on an inclined rotating  
372 drum and allows us to characterize the overall process efficiency. The present work thus  
373 defines several parameters for evaluating the screening efficiency of the rotating screen drum:  
374 the apparent screening efficiency ( $x_{11}+x_{22}+x_{33}$ ), the global process efficiency ( $x_{22}$ ), the impact  
375 of the processing on size distribution of products ( $100 (x_j - x_j^0) / x_j^0$ ), the contamination rate of  
376 the collected product targets ( $y_{21}$ ), and the loss rate of the product targets ( $z_{32}$ ).

377

378

### 379 *3.3. Impact of the parameters of the rotating drum*

380 We investigated the influence of the process parameters (angle on inclination, feed rate of wet  
381 agglomerates, and rotational speed) of the rotating screen drum on the screening efficiency  
382 parameters and on the impact on the characteristics of the rolled agglomerates. The results  
383 demonstrate monotonous variations of the experimental values when measured at the different  
384 values of the process parameters, even if the gap between the measured values is always not  
385 significantly different (Fig. 3-8).

386

387 *Influence of the angle of inclination* - An increase in the angle of inclination (from 5.1 to 12°)  
388 of the rotating drum induces slight changes of the screening efficiency parameters (Fig. 3).  
389 The description of the effects of the angle of inclination of the rotating drum can be divided in  
390 two parts on both side of the 6.2° angle. The higher values of the screening efficiency are  
391 observed at 6.2°, with 6.7% contamination rate and 6.7% loss rate, 39.7% apparent screening  
392 efficiency, and 93.6% global process efficiency. Beyond 6.2° of inclination, an increase in the  
393 angle of inclination until 12° of the rotating drum induces a decrease of the screening  
394 efficiency, with slight increases in the contamination rate and loss rate of the collected  
395 product targets and slight decreases in the apparent screening efficiency and global process  
396 efficiency. The lowest tested value of the inclination angle (5.1°) decreases the screening  
397 efficiency of the rotating screen drum, with high values of the contamination rate (17.1%) and  
398 loss rate (9.4%) of the collected product targets, and lower values of the apparent screening  
399 efficiency (88.7%) and global process efficiency (36.3%).

400

401 We evaluated the impact of the angle of inclination on the physicochemical characteristics of  
402 the agglomerates that are collected in the drawer 2 (Fig. 4). Angles of inclination between 6  
403 and 12° of the rotating drum does not affect the water content, the compactness and the

404 circularity of the agglomerates. However, the lowest value of the inclination angle ( $5.1^\circ$ )  
405 seems to generate a specific behaviour of the rotating screen drum, with slightly different  
406 measured values of water contents and compactness of the rolled agglomerated.

407

408 *Influence of the feed rate* - An increase of the feed rate (from 7 to 25 g/sec) inside the rotating  
409 drum only induces slight changes of the screening efficiency parameters (Fig. 5). An increase  
410 of the feed rate (from 7 to 17 g/sec) induces a decrease of the screening efficiency, with slight  
411 decreases of the apparent screening efficiency and global process efficiency and slight  
412 increases of the contamination rate and loss rate of the collected product targets. We do not  
413 observe significant changes of the screening efficiency parameters above a feed rate of 17  
414 g/sec.

415

416 We evaluated the impact of the feed rate on the main characteristics of the collected  
417 agglomerates (Fig. 6). An increase in the feed rate does not impact the water content and the  
418 compactness of the collected product targets, but slightly increases the circularity (from 0.65  
419 to 0.74) of the collected product targets.

420

421 *Effect of the rotational speed* - An increase of the rotational speed of the drum (from 2 to 27  
422 rpm) induces changes of the screening efficiency parameters (Fig. 7). The lowest value of the  
423 rotational speed (2 rpm) generates a specific behaviour of the rotating screen drum, with high  
424 values of contamination rate and loss rate of the collected product targets, and low value of  
425 the apparent screening efficiency. Above a value of 7 rpm, we observe a slightly effect of the  
426 rotational speed on the screening efficiency parameters. An increase of the rotational speed  
427 induces a decrease of the screening efficiency, with slight decreases in the apparent screening  
428 efficiency and global process efficiency and slight increases of the contamination rate and loss  
429 rate of the collected product targets. The transport mechanisms and the sieving efficiency are  
430 then not affected by the rotational speed.

431

432 We evaluated the impact of the rotational speed rate on the main characteristics of the rolled  
433 agglomerates (Fig. 8). An increase in the rotational speed does not significantly affect the  
434 water content and the compactness of the collected product targets. We only observed that a  
435 slight increase the circularity (from 0.50 to 0.65).

436

437

## 438 4. Discussion

439

440 The present investigation allows describing the functional roles of the rotating screen drum  
441 during processing of wet agglomerates of durum wheat semolina. We try to evaluate the  
442 different mechanisms: screening, secondary agglomeration, erosion/breakage, and rolling  
443 (Iveson et al., 2001), that could be promoted as a function of the process conditions. However,  
444 it remains difficult to evaluate the specific contribution of each mechanism, by only using the  
445 measured values of weights and the calculated mass fractions and the hydrotextural state of  
446 the three classes of agglomerates (Ruiz et al., 2011; Barkouti et al., 2014).

447

448

### 449 4.1. Apparent screening efficiency

450 The main function of the rotating screen drum is to screen a mixture of granular objects (Chen  
451 et al., 2010). The present results demonstrate high apparent screening efficiency of the  
452 rotating screen drum when used with wet agglomerates of durum wheat (Table 3), ranging  
453 between 89 and 96% depending on the process conditions. These high values indicate the  
454 high performance of the rotating screen drum in regards with its primary function of size  
455 separation. The presence of low amounts of under sized agglomerates in the second and third  
456 drawer can be associated to screening deficiency, as these agglomerates could flow over the  
457 two first screens, until the next ones. The transport phenomenon is maybe too fast to allow the  
458 sieving function to fully occur. Erosion or breakage mechanisms could also partly explain the  
459 gap with full screening efficiency if mechanical conditions lead to attempt the strength yield  
460 of agglomerates (Rondet et al., 2013).

461 The apparent screening efficiency of the rotating drum is affected by the process parameters  
462 (Fig. 3, 5, and 7). An increase of the angle of inclination and of the rotational speed slightly  
463 reduces the apparent screening efficiency due to a faster flow of the agglomerates inside the  
464 drum, inducing lower residence times on each screen for the sieving function (Rotich et al.,  
465 2015). At too low rotational speed (2 rpm), the transport mechanisms and the sieving  
466 efficiency are also affected. An increase of the feed rates (until 17 g/sec) slightly reduces the  
467 screening efficiency due to a more important load of agglomerates inside the drum, which  
468 reduces the frequency of the contacts of agglomerates on the screens, and thus reduces their  
469 opportunity to be sieved.

470 These high performances could be discussed in regard to the relatively low value of the global  
471 process efficiency, with range between 32 and 37% as a function of the process conditions

472 (Fig. 3, 5, and 7). These values are associated to the global process efficiency of both the wet  
473 agglomeration operation and the rolling operation. Almost similar values are found on the  
474 process industrial lines (Abecassis et al., 2012). The first wetting and agglomeration  
475 operations are known to be at the origin of the low efficiency of the couscous grains  
476 production at industrial scale, which is observed after the rotating drum.

477

478

#### 479 4.2. Impact on structuring mechanisms

480 The processing could generate specific mechanisms of secondary agglomeration and impact  
481 the mass fractions of the different collected fractions. The possible occurrence of secondary  
482 agglomeration was estimated by the changes of the values of the mass fractions of the  
483 collected small agglomerates, compared to the native mass fractions (Table 3) and also the  
484 hydrotextural analysis. The present study demonstrates very slight mechanisms of secondary  
485 agglomeration, with low decreases (between -13% and +2%) of the mass fractions of the  
486 small agglomerates, whatever the process conditions (data not shown). The agglomerates  
487 properties, the drum characteristics, and the process parameters do not allow generating  
488 enough efficient interactions between the soft agglomerates, to promote growing mechanisms  
489 by incorporating the small particles in larger agglomerates. Increasing the water content of the  
490 agglomerates and/or the mechanical stresses inside the drum could promote the secondary  
491 agglomeration mechanisms. In these conditions, the more plastic and sticky agglomerates  
492 could be involved in secondary agglomeration mechanisms under higher mechanical stresses.  
493 Moreover, if this phenomenon occurs, the resulting agglomerate will exhibit a mean  
494 hydrotextural state, between higher compactness/lower water content of the small particles  
495 and lower compactness/higher water content of the larger.

496 The impact of processing inside the rotating screen drum on the compactness and water  
497 content of the wet agglomerates can be discussed by using the hydro-textural diagram (Ruiz et  
498 al., 2011) (Fig. 9). This diagram is limited in its upper part by the saturation curve, which  
499 represents the maximum water content that a medium of a given constant compactness can  
500 contain. Before or after processing inside the drum, the increase in agglomerates size is  
501 concomitant with an increase in their water content and a decrease of their compactness.  
502 These relationships are similar to those obtained thanks to a classical wet agglomeration  
503 process (Rondet et al., 2010). Nevertheless, the agglomerates generated in this study and  
504 whatever the process parameters are found to be almost close to a water saturated state (Fig.  
505 9). The rotating screen drum process does not significantly impact the hydro-textural

506 parameters of the wet agglomerates, because almost no secondary agglomeration phenomena  
507 occur. In fact, the present experiments were realized in a range of process parameters (rotation  
508 speed, angle of inclination, and product flow rate) accessible by the experimental equipment.  
509 We were not able to test wider conditions because of experimental limits connected to the too  
510 slow or too fast flow of the product inside the drum. A possibility to generate secondary  
511 agglomeration mechanisms could be to increase the water content of the agglomerates to  
512 modify their characteristics (plasticity, fragility, stickiness, etc.).

513  
514 The powder flow inside the rotating drum could also induce some breakage and/or erosion  
515 mechanisms of the soft wet agglomerates. The occurrence of breakage and/or erosion was  
516 estimated by the changes of the values of the mass fractions of the collected large  
517 agglomerates, compared to the native mass fractions (Table 3). The present study  
518 demonstrates some mechanisms of erosion or breakage during processing, with decreases of  
519 the mass fractions of large agglomerates, which ranges between (between -4% and -40%) as a  
520 function of the process conditions (data not shown). The wet agglomerates of durum wheat do  
521 not resist to the mechanical stresses during processing inside the rotating screen drum (Rondet  
522 et al., 2013).

523  
524 The rolling effects are associated with possible changes in the structure and shape of the wet  
525 agglomerates of durum wheat. The presented results do not demonstrated a significant effect  
526 of the rotating screen drum on the compactness and water content of the wet agglomerates of  
527 durum wheat. The mechanical stresses distribution is not enough high during the powder flow  
528 inside the drum to promote shear stresses higher than their plastic yield on the agglomerates  
529 and also reduce their internal porosity by compression. On the other hand, a slight increase in  
530 the circularity values of the wet agglomerates (Table 3) is observed after processing inside the  
531 drum. This increase in circularity could be associated to the loss of surface irregularities on  
532 the agglomerates, according to the erosion mechanisms. The circularity increase is favoured  
533 by increasing the feed rate (Fig. 6) or the drum speed (Fig. 8). The rolling effect of the  
534 rotating drum is classically reported under industrial conditions and greatly contributes to the  
535 final sensory attributes of the couscous grains (Abecassis et al., 2012).

536  
537

538 *4.3. Dimensional analysis*

539 From the experimental study, we aimed in developing two empirical correlations gathering in  
 540 two unique process relationships all the experimental circularity (CIR) and apparent screening  
 541 efficiency ( $ASE = x_{11}+x_{22}+x_{33}$ ) obtained whatever the operating conditions used (drum speed,  
 542 angle of inclination and feed rate) by using the dimensional analysis. This approach makes it  
 543 possible to reduce the number of variables describing a physical problem using a set of  
 544 dimensionless ratios. The number of ratios originally used to describe the problem can be  
 545 obtained from the Buckingham theorem (Buckingham et al.1914).

546 The first step of dimensional analysis consists in establishing the list of relevant dimensional  
 547 parameters as remembered in the book of Delaplace et al. 2015. In the case of rotating drum,  
 548 the relevant dimensional parameters and their fundamental quantities are listed in Table 6.  
 549 The Buckingham theorem states that any physically meaningful equation involving  $n$   
 550 variables expressible in terms of  $k$  independent fundamental quantities can be rearranged into  
 551 an equivalent equation involving a set of  $p=n-k$  dimensionless variables, which are derived as  
 552 products of powers of the original variables. In our study, we have listed 9 variables ( $n$ ) that  
 553 can be expressed in terms of 3 fundamental quantities ( $k$ ). Following the procedure described  
 554 described in the book of Delaplace et al. (2015), the dimensional matrix (not shown) can be  
 555 obtained and permits to express the circularity and the screening efficiency according to ‘ $p=6$ ’  
 556 dimensionless variables.

557

558 The two physical phenomena refer to the equation:  $CIR = f(D, l, L_T, g, d_{50}, \rho, N, \alpha, D_b)$  and  
 559  $ASE = f(D, l, L_T, g, d_{50}, \rho, N, \alpha, D_b)$ . Applying Buckingham  $\pi$ -theorem, six dimensionless  $\pi$ -  
 560 terms were obtained:

561

$$562 \quad \pi_1 = \frac{D}{L_T} \quad (6)$$

$$563 \quad \pi_2 = \frac{l}{L_T} \quad (7)$$

$$564 \quad \pi_3 = \frac{d_{50}}{L_T} \quad (8)$$

$$565 \quad \pi_4 = \frac{N}{D^{-0.5}.g^{-0.5}} \quad (9)$$

$$566 \quad \pi_5 = \alpha \quad (10)$$

$$567 \quad \pi_6 = \frac{D_b}{\rho p .D^{2.5}.g^{0.5}} \quad (11)$$

568

569 The independent influences of the variation of each adimensional number on the value of CIR  
 570 and ASE were studied. This analysis made it possible to observe that values can be  
 571 mathematically described by:

$$572 \quad CIR \text{ or } ASE = f(\pi_4 = \frac{N}{D^{-0.5}.g^{0.5}} ; \pi_5 = \alpha ; \pi_6 = \frac{Db}{\rho p.D^{2.5}.g^{0.5}}) \quad (12)$$

573

574 The levels of each independent parameter considered for the experiment are given below:

575

$$576 \quad \pi_4 = 0.008, 0.028, 0.052, 0.075, 0.098$$

$$577 \quad \pi_5 = 0.088, 0.129, 0.169, 0.209$$

$$578 \quad \pi_6 = 0.000009, 0.000015, 0.000027, 0.000034$$

579

580 Fig. 10 depicts the adjustment between the values of the dimensionless circularity (CIR) and  
 581 apparent screening efficiency (ASE) described by models and those experimentally obtained,  
 582 whatever the process conditions. We found that the two proposed models (Eq. 13-14) describe  
 583 rather well the evolution of the circularity and the apparent screening efficiency. Indeed,  
 584 almost all experimental measurements are contained in a range corresponding to  $\pm 20\%$  of the  
 585 value predicted by the model.

586

$$587 \quad CIR = 0.073.Ln(\pi_4) + 0.567.\pi_5^{0.081} + 0.621.\pi_6^{0.043} + 0.06 \quad (13)$$

$$588 \quad ASE = 90,0.e^{(-0,05.\frac{\ln(\frac{\pi_4}{0,06})}{2,59})^2} \quad (14)$$

589

590 The values taken by Eq. 13-14 parameters make it possible to highlight the influence of  
 591 process conditions. The circularity and the apparent screening efficiency are mainly affected  
 592 by the drum speed and the angle of inclination. According to this mechanism, it has been  
 593 possible to develop two original and descriptive models based on an adimensional approach.  
 594 Unique equations were proposed whatever the process condition and are associated with sets  
 595 of coefficients. In order to improve the physical understanding of the underlying  
 596 phenomenon, an experimental approach specially designed to allow the establishment of  
 597 regime maps through a physical approach and the identification of dimensionless numbers  
 598 *e.g.* a ratio between a transport speed and a sieving speed could be further carried out.  
 599 Nevertheless we can notice that it could be difficult to found explicit experimental conditions  
 600 which lead to decrease the screening efficiency (less than 80%).

601

602

**603 5. Conclusion**

604

605 A matrix analysis allows describing the population balance of the mass sieved by a rotating  
606 screen drum and also taking into account the functional roles of operation during processing  
607 of wet agglomerates of durum wheat semolina. Results highlight that high apparent screening  
608 efficiency of the rotating screen drum ranging between 89 and 96% depending on the process  
609 conditions. These high values indicate the high performance of the rotating screen drum in  
610 regards with its primary function of size separation.

611 The rotating screen drum process does not significantly impact the hydro-textural parameters  
612 of the wet agglomerates as no secondary agglomeration phenomena significantly occur. A  
613 dimensional analysis is conducted to purpose relationships based, between the circularity on  
614 the one hand and the screening efficiency on the other hand and the process parameters.  
615 Nevertheless in order to improve the physical understanding of the underlying phenomenon,  
616 an experimental approach with more experimental points could be further carried out.

617

618

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620

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623

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Table 1. Physicochemical characteristics of the initial wet grains made of durum wheat semolina, just before the rolling process in the rotating drum.

	Mass fraction ( $x_i$ )	Water content (g / g dry matter)	Compactness (-)	Circularity (-)
Wet grains	--	0.420 ( $\pm 0.010$ ) <sup>b</sup>	0.597 ( $\pm 0.006$ ) <sup>b</sup>	--
Small fraction (diameter < 1 mm)	0.483 ( $\pm 0.026$ ) <sup>b</sup>	0.398 ( $\pm 0.010$ ) <sup>a</sup>	0.614 ( $\pm 0.004$ ) <sup>c</sup>	--
Medium fraction (1 mm < diameter < 2 mm)	0.285 ( $\pm 0.066$ ) <sup>a</sup>	0.408 ( $\pm 0.010$ ) <sup>a</sup>	0.606 ( $\pm 0.005$ ) <sup>bc</sup>	0.636 ( $\pm 0.140$ )
Large fraction (2 mm < diameter)	0.232 ( $\pm 0.052$ ) <sup>a</sup>	0.473 ( $\pm 0.010$ ) <sup>a</sup>	0.573 ( $\pm 0.011$ ) <sup>a</sup>	--

Values are means ( $\pm$  standard deviation).

Values in column with the same letter were not significantly different ( $P < 0.05$ ).

Table 2. Physicochemical characteristics of the three classes of wet agglomerates of durum wheat semolina, collected after the rolling process.

	Water content (g / g dry matter)	Compactness (-)	Circularity (-)
Agglomerates in drawer 1 (d < 1 mm)	0.410 ( $\pm 0.005$ ) <sup>a</sup>	0.654 ( $\pm 0.028$ ) <sup>c</sup>	--
Agglomerates in drawer 2 (d < 2.2 mm)	0.425 ( $\pm 0.003$ ) <sup>b</sup>	0.609 ( $\pm 0.060$ ) <sup>b</sup>	0.668 ( $\pm 0.084$ )
Agglomerates in drawer 3 (2.2 mm < d)	0.434 ( $\pm 0.004$ ) <sup>b</sup>	0.571 ( $\pm 0.020$ ) <sup>a</sup>	--

Values are means ( $\pm$  standard deviation).

Values in column with the same letter were not significantly different ( $P < 0.05$ ).

Table 3. Calculated mass fractions ( $x_i$  and  $x_{ij}$ ) of the collected agglomerates  $i$  and their fractions  $j$ , over the total mass ( $m$ ) of collected product, after the processing inside the rotating screen drum.

	Agglomerates in drawer $i=1$ ( $d < 1$ mm)	Agglomerates in drawer $i=2$ ( $d < 2.2$ mm)	Agglomerates in drawer $i=3$ ( $2.2$ mm $< d$ )	<i>Total collected agglomerates</i>
Small agglomerates $j=1$ ( $d < 1$ mm)	0.368	0.043	0.006	0.417
Medium agglomerates $j=2$ ( $1$ mm $< d < 2$ mm)	0	0.332	0.027	0.359
Large agglomerates $j=3$ ( $2$ mm $< d$ )	0	0	0.223	0.223
<i>Total collected agglomerates</i>	0.368	0.375	0.256	1

Table 4. For each collected agglomerates  $i$ , calculated mass fractions ( $y_{ij}$ ) of their fractions  $j$ , over the total mass of collected product in the drawer  $i$ , after the processing inside the rotating screen drum.

	Agglomerates in drawer $i=1$ ( $d < 1$ mm)	Agglomerates in drawer $i=2$ ( $d < 2.2$ mm)	Agglomerates in drawer $i=3$ ( $2.2$ mm $< d$ )
Small agglomerates $j=1$ ( $d < 1$ mm)	1	0.115	0.023
Medium agglomerates $j=2$ ( $1$ mm $< d < 2$ mm)	0	0.885	0.104
Large agglomerates $j=3$ ( $2$ mm $< d$ )	0	0	0.873
<i>Total collected agglomerates</i>	<i>1</i>	<i>1</i>	<i>1</i>

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Table 5. For each fraction  $j$ , calculated mass fractions ( $z_{ij}$ ) of their distribution in the drawer  $i$ , over the total mass of fraction  $j$ , after the processing inside the rotating screen drum.

	Agglomerates in drawer $i=1$ ( $d < 1$ mm)	Agglomerates in drawer $i=2$ ( $d < 2.2$ mm)	Agglomerates in drawer $i=3$ ( $2.2$ mm $< d$ )	<i>Total collected agglomerates</i>
Small agglomerates $j=1$ ( $d < 1$ mm)	0.883	0.103	0.014	<i>1</i>
Medium agglomerates $j=2$ ( $1$ mm $< d < 2$ mm)	0	0.926	0.074	<i>1</i>
Large agglomerates $j=3$ ( $2$ mm $< d$ )	0	0	1	<i>1</i>

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Table 6. Definition of the starting variables and fundamental quantities used for the dimensional analysis.

Dimensional variables	Symbol	Fundamental quantities		
		M	L	T
Length of the screen	$l$	0	1	0
Opening mesh size	$L_T$	0	1	0
Diameter of the cylinder	$D$	0	1	0
Acceleration of gravity	$g$	0	1	-2
Median diameter of agglomerates	$d_{50}$	0	1	0
Density of agglomerates	$\rho$	1	-3	0
Drum speed	$N$	0	0	-1
Angle of inclination	$\alpha$	0	0	0
Feed rate	$D_b$	1	0	-1
Circularity	CIR	0	0	0
Apparent screening efficiency	ASE	0	0	0

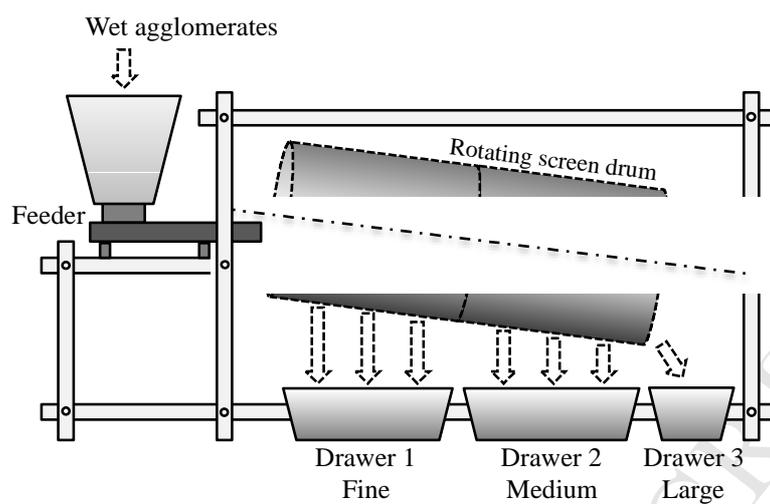


Fig. 1. Schematic representation of the experimental rotating screen drum.

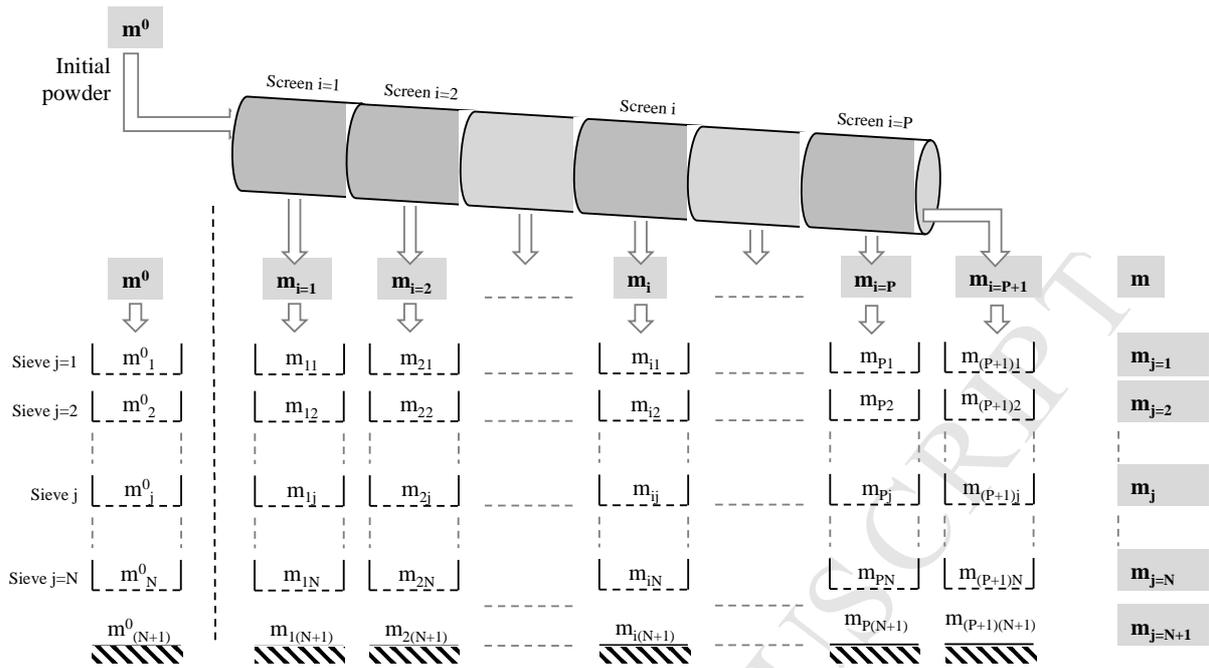


Fig. 2. Schematic representation of the specific method to quantify the screening efficiency of a rotary screen drum by using a matrix analysis.

## CORRECTED GRAPHS

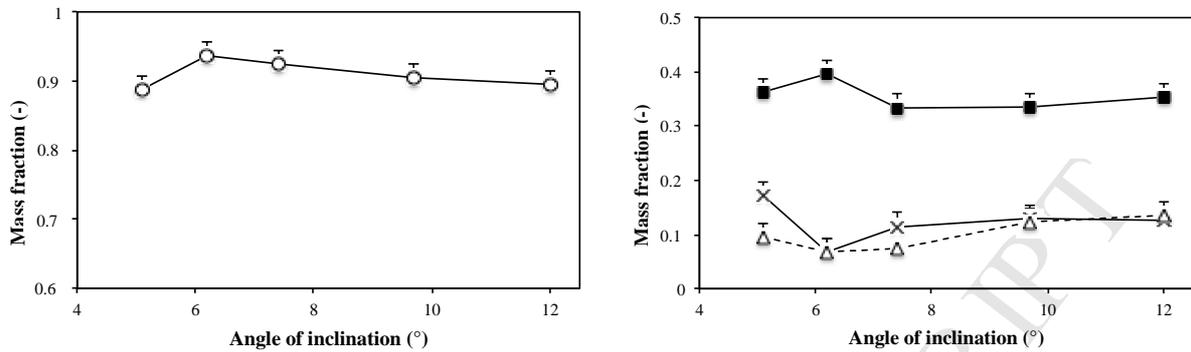


Fig. 3. Impact of the angle of inclination of the rotating screen drum on the screening efficiency parameters: apparent screening efficiency ( $x_{11}+x_{22}+x_{33}$ ; O), global process efficiency ( $x_{22}$ ; ■), contamination rate of the collected product targets ( $y_{21}$ ; ×), and loss rate of the collected product targets ( $z_{32}$ ; Δ).

## CORRECTED GRAPHS

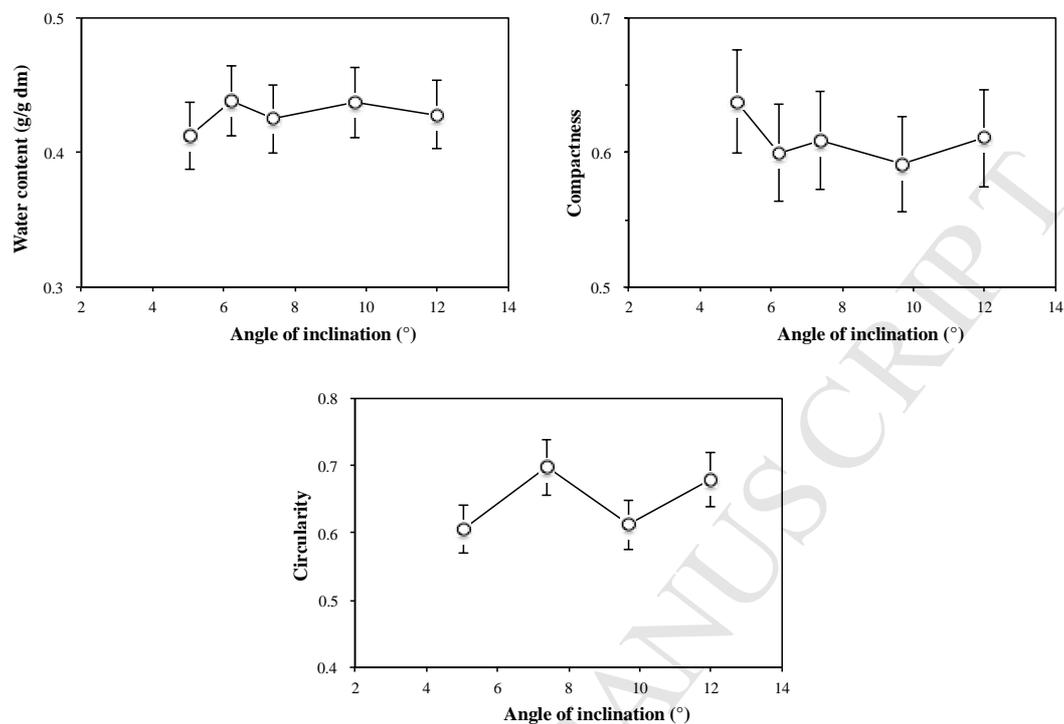


Fig. 4. Impact of the angle of inclination of the rotating screen drum on the physicochemical characteristics (water content, compactness, and circularity) of the rolled agglomerated collected in the drawer 2.

## CORRECTED GRAPHS

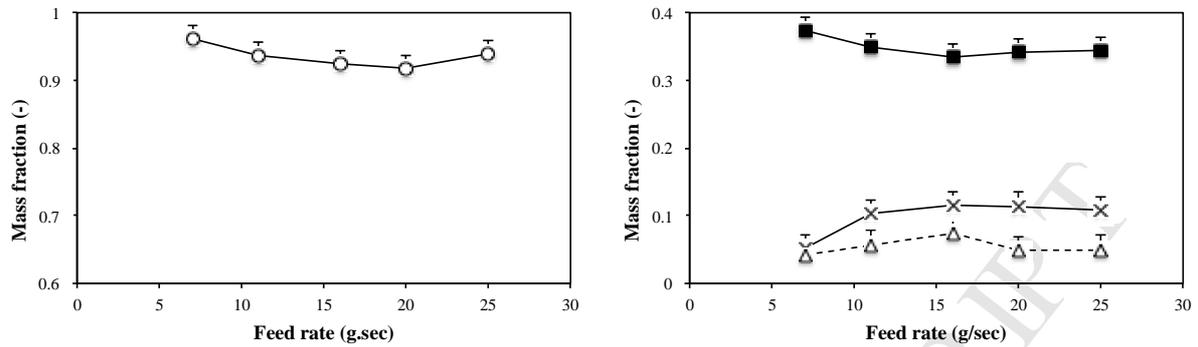


Fig. 5. Impact of the feed rate of the rotating screen drum on the screening efficiency parameters: apparent screening efficiency ( $x_{11}+x_{22}+x_{33}$ ; ●), global process efficiency ( $x_{22}$ ; ■), contamination rate of the collected product targets ( $y_{21}$ ; ×), and loss rate of the collected product targets ( $z_{32}$ ; Δ).

## CORRECTED GRAPHS

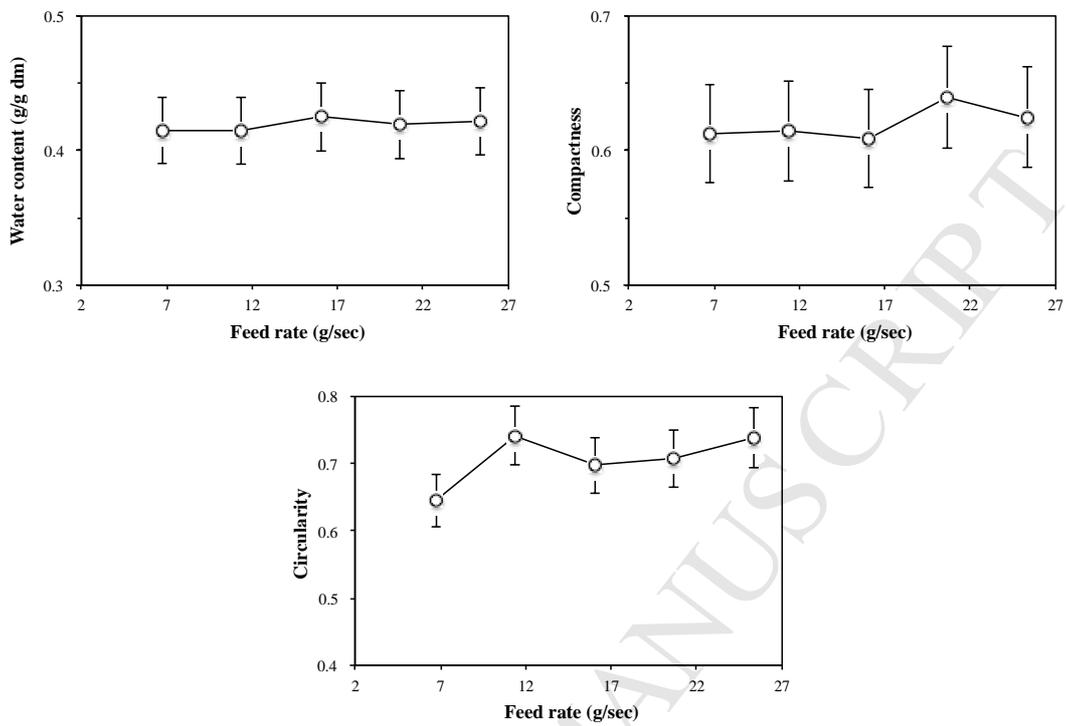


Fig. 6. Impact of the feed rate of the rotating screen drum on the physicochemical characteristics (water content, compactness, and circularity) of the rolled agglomerated collected in the drawer 2.

## CORRECTED GRAPHS

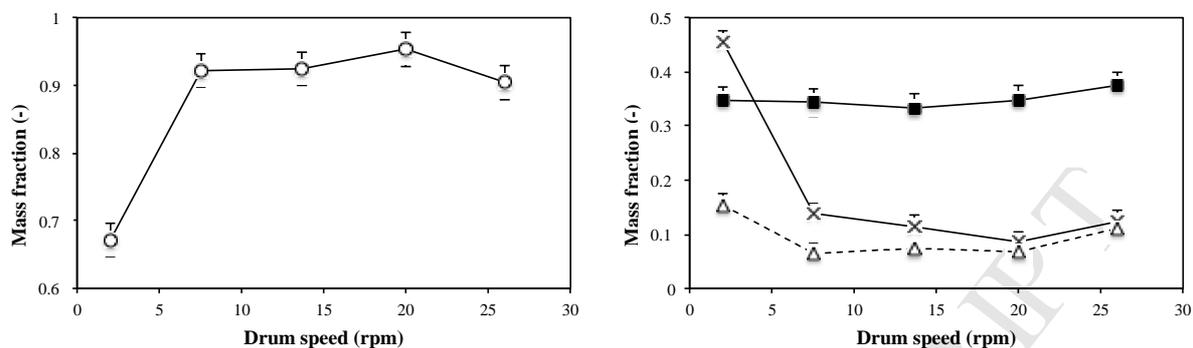


Fig. 7. Impact of the drum rotational speed on the screening efficiency parameters: apparent screening efficiency ( $x_{11}+x_{22}+x_{33}$ ; O), global process efficiency ( $x_{22}$ ; ■), contamination rate of the collected product targets ( $y_{21}$ ; ×), and loss rate of the collected product targets ( $z_{32}$ ; Δ).

## CORRECTED GRAPHS

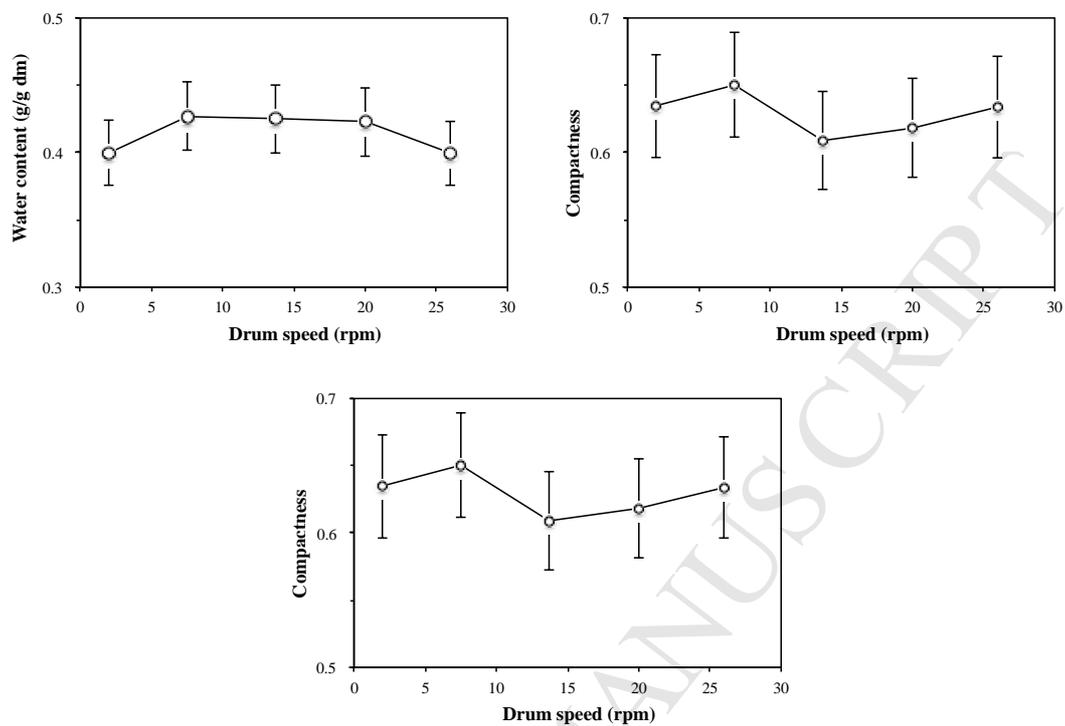


Fig. 8. Impact of the drum rotational speed, on the physicochemical characteristics (water content, compactness, and circularity) of the rolled agglomerated collected in the drawer 2.

## CORRECTED GRAPHS

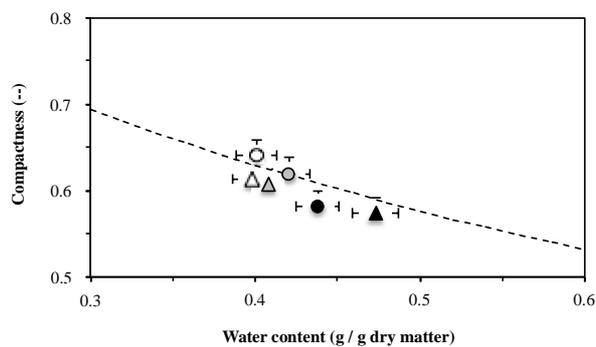


Fig. 9. Hydro-textural description (compactness vs. measured water content) of the small ( $\circ\Delta$ ), medium ( $\circ\Delta$ ), and large ( $\bullet\blacktriangle$ ) wet agglomerates, before ( $\Delta\Delta\blacktriangle$ ) and after ( $\circ\circ\bullet$ ) processing inside the rotating screen drum. The saturation curve is dotted points.

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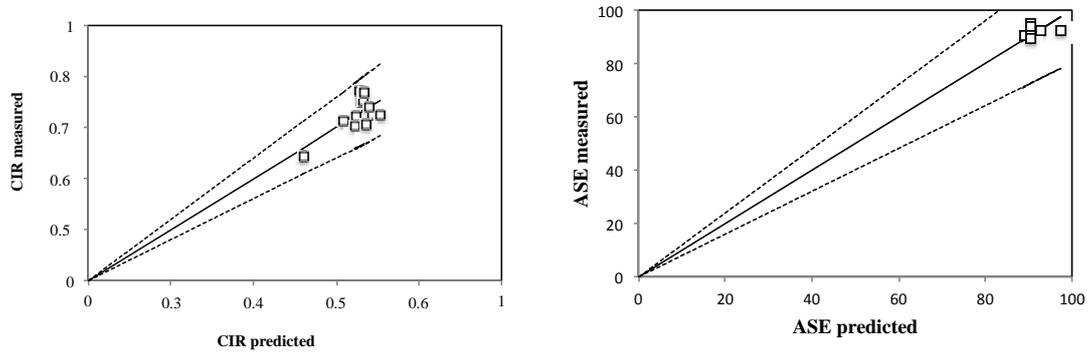


Fig. 10. Comparison of measured circularity (CIR) and apparent screening efficiency (ASE) with predicted values from Eq. (13) and Eq. (14).

**Highlights**

Screening efficiency of a rotating drum is measured by an original matrix analysis.

The rotating drum is very efficient to screen wet soft agglomerates of wheat.

The compactness and shape of the agglomerates are affected by the rolling process.

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Belloq, B., Ruiz, T., Delaplace, G., Duri, A., Cuq, B. (2017). Screening efficiency and rolling effects of a rotating screen drum used to process wet soft agglomerates. *Journal of Food Engineering*, 195, 235-246. DOI : 10.1016/j.jfoodeng.2016.09.023