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1 **Innovative non-destructive sorting technique for juicy stone fruits: textural properties of**
2 **fresh mangos and purees**

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17
18 **Abstract**

19 Mango has an abundant production leading to important post-harvest losses. Mango
20 processing is an alternative to reduce these losses. Nowadays, the lack of instrumental tools
21 suitable to sort mangos according to their ability to be processed into products with specific
22 quality is a main setback for their processing. The aim of this study was to develop new tools,
23 mainly non-destructive, to sort easily fresh mangos according to their maturity stage and to
24 the specific properties of their purees. To this end, an innovative experimental strategy
25 combining textural, rheological and physico-chemical analyses was proposed to characterize
26 mangos and their purees. Results showed that mango firmness is a great indicator of mango
27 heterogeneity and has an important impact on the properties of mango purees. A non-
28 destructive compression test was reliable to measure accurately mango firmness and to
29 anticipate rheological and particles size properties of mango purees.

30
31 **Abbreviations**

32 D_{5N} and D_{10N}, distance of compression at 5 and 10 N (mm); DM, dry matter (g /100 g puree);

33 D₁₀, particles size for which 10% of the particles have a size smaller than this diameter (µm);

34 D₅₀, particles size for which 50% of the particles are smaller than this diameter (μm); D₉₀,
35 particle size for which 90% of the particles are smaller than this diameter (μm); D [3;2],
36 surface area average diameter or Sauter mean diameter : the diameter of a sphere that has the
37 same volume/surface ratio as the set of particles (μm); D [4;3], volume mean diameter or
38 Brouckere mean diameter : the diameter of a sphere whose volume is equal to the average
39 volumes of all the particles in the sample (μm); F_{max}, maximum value of the peak force (N); g,
40 gravitational acceleration (m.s⁻²); G', storage modulus (Pa); G'', loss modulus (Pa); K, the
41 consistency index (Pa.sⁿ); n, the flow behavior index, pH, potential hydrogen; RH, relative
42 humidity (%); rpm, revolutions per minute; TA, titratable acidity (g citric acid/100g puree);
43 TSS, total soluble solids (°Bx); μ, dynamic viscosity (Pa.s).

44

45 **Keywords**

46 Mango, purees, texture, rheology, maturity, sorting tool

47

48

49

50 1. Introduction
51

52 *Mangifera indica* L. known as mango, is a tropical fruit originated from the Indo-Burmese
53 region. Mango is one of the most produced (mainly in India, China, Thailand, Indonesia and
54 Pakistan) and consumed fruits worldwide after banana (Chantalak and Robert E, 2017; Masud
55 Parvez, 2016). There is a large variety of mangos that differ in size, color, texture, and
56 nutritional properties. The most consumed mangos varieties are Kent, Keitt, Haden, Tommy
57 Atkins, Cogshall, Alphonso, Amelie and Valencia pride (Djioua et al., 2010).

58 According to the FAO statistics, mango production worldwide increased by 26 million metric
59 tons over a period of 17 years to reach 50 million metric tons in 2017 (FAO, 2019). In
60 developing countries, post-harvest fruit losses due to the abundant mango production can be
61 estimated up to 40% (Boateng, 2016; Memon et al., 2013). Hence, processing and
62 transforming mangos into purees, juices, jams, canned products and dried slices (Evans et al.,
63 2017) is an alternative not only to minimize post-harvest losses but also to provide local
64 incomes. Nevertheless, the quality of processed products (physical, physico-chemical and
65 organoleptic characteristics) depends on the maturity stage of raw mangos (Ellong et al.,
66 2015). Indeed, the heterogeneity of the maturity stages encountered in a same batch of
67 mangos for processing constitute a barrier for controlling the process and the quality of the
68 finished product (Rivier et al., 2009)

69 In the light of the above, fruit sorting prior to mango processing is generally performed in
70 processing units to reduce batch heterogeneity in relation with maturity stages. To date,
71 mango sorting is mainly manual, time consuming and highly labor-dependent (visual and
72 tactile know-how) leading in some cases to inaccurate fruits sorting and disparate quality of
73 processed products. Several tools (e.g. textural, spectral, fluorescence and biochemical
74 measurements) have been evaluated to predict the maturity stage or the quality of mango
75 fruits (Pronprasit and Natwichai, 2013; Valente et al., 2011; Zakaria et al., 2012). However, as
76 far as the authors are aware, in these studies, **none of the proposed tools were conceived as to**
77 **predict the quality of processed products.**

78 Nowadays, the lack of instrumental tools suitable to sort mango fruits according to their
79 ability to be processed into products with specific quality is a main setback for up-grading
80 mango fruits. In this context, the aim of this work was to develop new methods and tools,
81 mainly non-destructive, allowing to sort mangos according not only to their maturity stage but
82 also to the specific properties of their processed products (puree). To this end, an

83 experimental strategy combining mechanical (rheology and texture), physical and physico-
84 chemical (particles size measurement, color, pH, titratable acidity, °Bx, dry matter) analyses
85 was proposed to characterize fresh mangos and mango purees. Firstly, textural (penetrometry
86 and compression), rheological (oscillatory), physical (weight, density) and color analyses
87 were performed on fresh mangos at different stages of maturity. In a second place, fresh
88 mangos were processed into purees that were characterized (particles size, rheology and
89 physico-chemistry). Finally, statistical analyses were used to (i) identify pertinent
90 instrumental indicators that describe the maturity stages of mangos, (ii) evaluate the impact of
91 mangos maturity stage on purees characteristics and finally to (iii) propose new tools for
92 sorting fresh mangos according to their ability to be processed into purees.

93 2. Materials and methods

94 2.1 Fruits

95
96 Fifty green mangos (*Mangifera indica* L., cv. Kent, Peru) previously stored at 10°C during 10
97 days (to slow down maturation) were purchased from a local warehouse (Georges Helfer SA,
98 Plan d'Orgon, France). All mangos were stored in controlled conditions (18°C, 80% RH)
99 between one and twenty-five days. Daily, one or two fruits were characterized. Each mango
100 was transformed separately into puree and all measurements were carried out on the same
101 fruit and its puree. Data of twenty-eight mangos were selected for this study.

102 2.2 Fresh mango characterization

103
104 Before the analyses, mango fruits, were soaked in chlorinated water (200 ppm sodium
105 hypochlorite, Chem-Lab, Zedelgem, Belgium) and wiped with 70% ethanol (Honeywell,
106 Riedel-de Haën, absolute, ≥ 99.9, Charlotte, North Carolina, USA) in order to remove the
107 latex layer that covers the fruits (Palafox-Carlos et al., 2012; Penchaiya et al., 2015).

108 2.2.1 Fruit density

109
110 Fruit density was calculated using Archimedes' principle by measuring the fresh fruits mass in
111 air and in water (each mango was placed in a basket hanging from the balance and fully
112 immersed in water) according to the method described by Joas et al., 2009 (Joas et al., 2009).

113

114 2.2.2 Texture analysis

115

116 Firmness of mangos was measured using a texture analyzer (TA-XT2, Stable micro Systems,
117 London, UK) equipped with a 5 kg load cell and an Exponent software (version 5.1.1.0) to
118 record data.

119 Two different methods were evaluated: a non-destructive compression test and a destructive
120 penetrometry test.

121 2.2.2.1 Non-destructive compression test

122

123 The compression test in this study was proposed to simulate the tactile perception of the
124 operator during sorting mango fruits according to their firmness. Compression tests were
125 performed on both larger sides of mango since water potential of the two sides may differ due
126 to the position of the fruit on the tree and to its exposition to the sun. Measurements were
127 performed on three different positions on each side of the fruit. The test was carried out to
128 reach a maximum compression force of 10 N with a 2 cm spherical probe and probe speed of
129 $1 \text{ mm}\cdot\text{s}^{-1}$. The maximum force was carefully chosen in order to avoid damaging the fruit
130 structure and subsequently proposing a non-destructive test. The obtained force-distance
131 curves were recorded and the distances of compression (D_{5N} or D_{10N}) at 5 or 10 N were
132 identified as the most consistent parameters to describe mango firmness. Similar results of
133 D_{5N} and D_{10N} values were recorded regardless the side of mango ($R^2 > 0.99$) for linear
134 correlations of D_{5N} data and D_{10N} data for side 1 and side 2 (data not shown). Considering this
135 observation, results concerning compression tests will be presented only for D_{5N} and for one
136 side in the following.

137 2.2.2.2 Destructive penetrometry test

138

139 Penetrometry test was performed on slices ($h=15 \text{ mm}$, using an electric ham slicer generally
140 used for processed meat) from each side of mango using a cylindrical stainless steel probe of
141 5 mm diameter. The test was carried out on the inner flesh tissue to reach a maximum
142 distance of 5 mm with a probe speed of $1 \text{ mm}\cdot\text{s}^{-1}$. The aim of this additional test was to
143 evaluate the firmness of the mango flesh in a destructive way as it is conventionally done. The
144 firmness of mangos was evaluated by the average of the maximum value of the peak force
145 (F_{max}) of the resulting force-distance curves. Measurements were realized on three different
146 positions of the slice.

147 2.2.3 Rheological measurements

148

149 Rheological measurements were carried out on cylindrical mango slices (2 mm thickness and
150 35 mm diameter) cut using an electric ham slicer generally used for processed meat.

151 Rheological measurements were performed using a Haake Mars 60 rheometer (Thermofisher,
152 Waltham, Massachusetts, USA) equipped with a 35 mm serrated parallel plates geometry and
153 a “RheoWin” software (version 4.82.0002) to record rheological data. A strain amplitude
154 sweep test was performed in low strain amplitude range (from 0.01 to 1%) at a constant
155 frequency of 1 Hz and a controlled normal force of 4 N. All experiments were conducted at
156 temperature of $25^{\circ}\text{C} \pm 0.1$ controlled by a Peltier system. The storage modulus values G' (Pa)
157 at 0.1% of strain were selected as rheological indicator reflecting the solid-like behavior of
158 mango slices. Measurements were performed in quadruplicate.

159 2.2.4 Flesh color

160 Color was determined on grinded flesh using a Minolta CR-300 colorimeter (Konica Minolta
161 Sensing, Inc, Ramsey, New Jersey, USA) according to the CIELAB color system (L^* , a^* , b^*).
162 L^* represents the lightness varying from 0 to 100, (0 representing black and 100 representing
163 white), a^* represents the variation from green (-) to red (+) and the b^* reflects the variation
164 from blue (-) to yellow (+).

165 2.3 Characterization of mango puree

166 2.3.1 Puree preparation

167
168 Each mango was manually peeled, the seed was removed and the flesh was cut into small
169 pieces (around 1 cm^3). The flesh was grinded at 25°C with a Thermomix (Vorwerk, Typ 31-1,
170 Wuppertal, Germany) at a speed of 1000 rpm for 1 min, 7000 rpm for 1 min and 10000 rpm
171 for 2 min. After grinding, the puree (approximately 180g) was stored at 4°C before the
172 analyses.

173 2.3.2 Rheological measurements

174 175 2.3.2.1 Rotational measurements

176 Rotational measurements of mango purees were performed using a Physica MCR301
177 rheometer (Anton Paar GmbH, Graz, Austria) equipped with “Start Rheoplus” software
178 (version RHEOPLUS/32 V3.40) to record the rheological data. A six blades vane geometry
179 (ST22- 6V- 16, radius of 22 mm) was used with stationary cup with a radius of 27 mm giving
180 a gap of 2.5 mm. The shear rate varied from 0.1 to 500 s^{-1} and temperature was held at $25^{\circ}\text{C} \pm$

181 0.1 using a Peltier system. The evolution of dynamic viscosity μ (Pa.s), of each mango puree,
182 as function of the shear rate $\dot{\gamma}$ (s^{-1}) was recorded.

183 2.3.2.2 Oscillatory measurements

184 Strain amplitude sweep tests were conducted using the Haake Mars 60 rheometer equipped
185 with a 35 mm serrated parallel plates geometry. Frequency was held constant at 1 Hz, while
186 strain amplitude varied between 0.01 and 100%. All experiments were conducted at a
187 temperature of $25^{\circ}\text{C} \pm 0.1$ controlled by a Peltier system. For each puree, the storage and loss
188 moduli G' and G'' were recorded as function of the strain (%). The values of the storage G'
189 (Pa) and loss G'' (Pa) moduli (at 1% of strain in the linear viscoelastic domain) were selected
190 as rheological indicators reflecting the solid-like behavior and liquid-like behavior of mango
191 purees, respectively.

192 2.3.3 Particles size measurements of suspended insoluble solids

193
194 Particles size distribution was determined by LASER diffraction using a Malvern Mastersizer
195 (Mastersizer 3000, Malvern Instruments Limited, Worcestershire, UK). This particles size
196 analyzer can provide theoretically particles size distribution from 10 nm to 3500 μm .
197 Measurements were carried out in a wet-mode using distilled water as the suspension
198 medium. The values 1.73 and 1.33 were used for the refractive indices of cloud particles and
199 dispersion phase (water), respectively, and 0.1 was used for the absorption index of cloud
200 particles (Dahdouh et al., 2016). Samples were introduced into the volume presentation unit,
201 which already contained deionized water (obscuration of 20%). In this unit, the diluted sample
202 was stirred at 1500 rpm and pumped through the optical cell. The initial particles size
203 distribution of puree was verified to be not modified in such conditions of stirring and
204 pumping. For each measurement, size distribution (volume density against particles size) was
205 provided and statistical volume diameters, D_{10} , D_{50} and D_{90} were given (D_x indicates a
206 particles size for which x% of the particles are below that size). The surface area average
207 diameter $D [3;2]$ (Sauter mean diameter) and the volume mean diameter $D [4;3]$ (Brouckere
208 mean diameter) were also provided (Dahdouh et al., 2015).

209
210 The $D [3;2]$ indicates the diameter of a sphere that has the same volume/surface ratio as the
211 set of particles Eq. (1):

$$212 \quad D [3;2] = \frac{\sum_i n_i d_i^3}{\sum_i n_i d_i^2} \quad (1)$$

213 The D [4;3] indicates the diameter of a sphere whose volume is equal to the average volumes
214 of all the particles in the sample Eq. (2):

$$215 \quad D [4;3] = \frac{\sum_i n_i d_i^4}{\sum_i n_i d_i^3} \quad (2)$$

216 With n_i the number of particles of diameter d_i .

217 Particles size measurements performed separately on mango purees and on their isolated
218 suspended insoluble solids (centrifugation 18000 g /30 min) provided identical particles size
219 distributions, smaller compounds being not detectable in the Mastersizer operating conditions.
220 Hence, results presented in this work concern mainly the particles size distribution of
221 suspended insoluble solids ($> 1\mu\text{m}$) of purees.

222 2.3.4 Physico-chemical analyses

223 **Mango is a climacteric fruit for which biochemical and nutritional changes occurring during**
224 **tree-ripening can continue after harvesting.** Titratable acidity (TA), total soluble solids (TSS)
225 and dry matter (DM) were performed on purees according to protocols and methods used for
226 fruit suspensions (Dahdouh et al., 2016). pH and titratable acidity were measured using an
227 automatic Titroline apparatus (Schott Schweiz AG, St. Gallen, Switzerland). Titratable acidity
228 was assessed by titration with 0.025 N NaOH until a pH 8.2. **Titratable acidity (TA) was**
229 **expressed in g of citric acid /100 g of puree since it is well known that citric acid is one of the**
230 **major organic acids present in mango contributing to fruit acidity and flavor.** Total soluble
231 solids (TSS, expressed in °Bx) were measured with an Abbe refractometer (Atago, Japan).
232 Dry matter (DM, expressed in g/100 g of puree) was determined by drying 3 g of puree at
233 70°C under vacuum for 24 h.

234 For all physico-chemical analyses, measurements were performed at 25°C in triplicate and the
235 average values were used.

236 2.4 Statistical analyses

237 Multivariate analyses were carried out using XLSTAT (version 16.0.4744 Addinsoft, Paris,
238 France). **Principal component analysis (PCA), a multivariate projection method designed to**
239 **reduce the dimensionality and to describe the variation of the data (Azira et al., 2014), was**
240 **performed to analyze the total variability between samples and to identify groups with similar**
241 **characteristics among fresh mangos and puree.** Eight indicators for fresh mango (F_{max} , D_{5N} ,
242 G' , L^* , a^* , b^* , weight, density) and twelve indicators for purees (particles size: D [3;2], D
243 [4;3], D_{10} , D_{50} , D_{90} ; rheological behavior: G' , G'' , K, n and physico-chemical characteristics:

244 TA, TSS and DM) were set as variables. The score plot was extracted from the first two
245 principal components, PC 1 and PC 2, as they presented the maximum variability of the data.

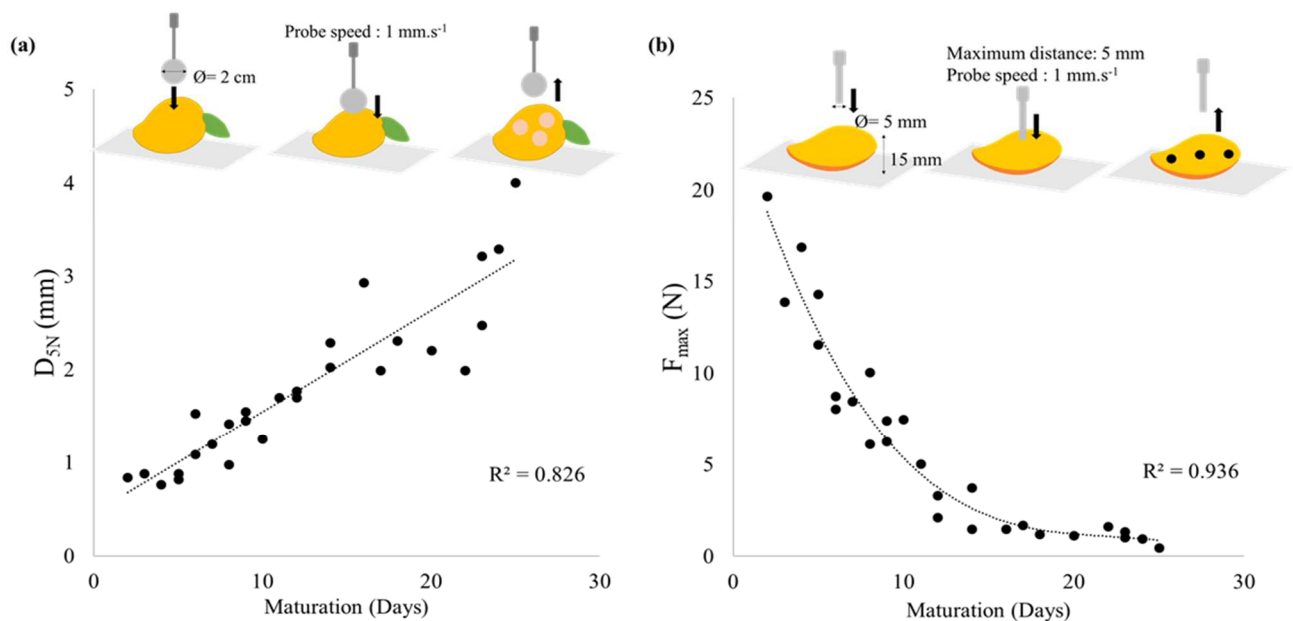
246 3. Results and discussion

247 3.1 Fresh mangos

248 3.1.1 Texture characterization

249 Results regarding compression test are presented in Fig. 1(a). The distance achieved by the
250 probe when applying 5 N (D_{5N}) on the raw mango increased significantly with maturation
251 highlighting a significant loss of mango firmness. The loss of firmness of fruits occurring
252 during the maturation period could be due to biochemical changes such as the degradation of
253 pectins, cellulose and hemicellulose (Lawson et al., 2019; Padda et al., 2011; Yashoda et al.,
254 2006).

255 Fig. 1(b) shows that the force (F_{max}) needed to puncture 15 mm of mango slice decreased
256 significantly during maturation confirming the loss of firmness. However, penetrometry test
257 seems to be less discriminating regarding mango firmness than compression test after 15 days
258 of maturation. Indeed, a significant decrease of F_{max} (92%) was observed before 15 days of
259 maturation whereas beyond this maturation stage the F_{max} was almost steady. After 15 days,
260 the difference of the flesh firmness was not high enough to be detectable by the penetrometry
261 test. Contrariwise, in the case of compression test, the firmness of the whole fruit (peel and
262 flesh) was measured, leading to better results.



263

264 Fig. 1. Evolution of (a) D_{5N} (mm) and (b) F_{max} (N) during maturation.

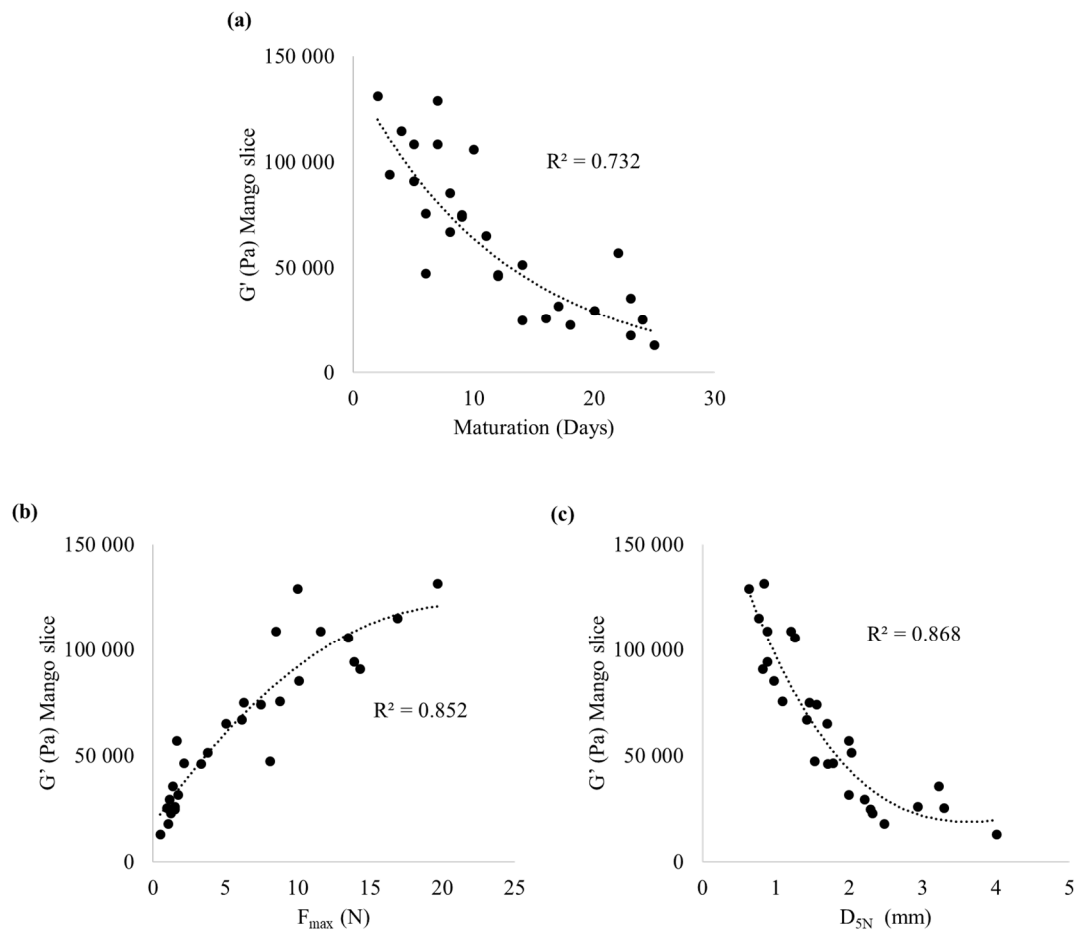
265 3.1.2 Rheological characterization

266 Since texture tests showed that the firmness of mango flesh decreased during maturation,
267 rheological measurements were performed to assess the evolution of the solid-like behavior of
268 mango flesh in relation with firmness loss during maturation. To this end, the storage modulus
269 G' (Pa) reflecting the solid-like behavior of a material was evaluated through oscillatory test
270 in small amplitude range (0.1 to 1%) within the linear viscoelastic range (Lee, 2018).

271 Fig. 2 (a) depicts the evolution of the storage modulus G' (Pa) as function of maturation days
272 showing that the solid-like behavior of mango flesh decreased significantly during maturation.
273 Indeed, the storage modulus of mango slices at the end of maturation was 10 times lower than
274 the one recorded for green mango at early maturation stages. This observation emphasizes
275 that biochemical and physico-chemical phenomena (starch, cell wall, cellulose and
276 hemicellulose degradation, etc.,) (Nambi et al., 2016) occurring during maturation led to a
277 modification of the viscoelastic properties of mango flesh and subsequently to its loss of
278 firmness.

279 Moreover Fig. 2 (b) and (c), point up interesting correlations between the solid-like behavior
280 (G') of mango flesh and the firmness of mango flesh (F_{\max}) and the firmness of the whole fruit
281 (D_{5N}). It is important to notice that the D_{5N} is a better indicator than F_{\max} regarding the solid-
282 like behavior of mango flesh at stages of maturation above 10 days (when $F_{\max} < 5$ N), Fig. 2
283 (b) and (c). This result confirms that it is possible to trace back the solid-like behavior of

284 mango flesh by performing a simple and non-destructive compression test on the whole fruit.



285
286 Fig. 2. Evolution of the storage modulus G' (Pa) of mango slices as function of (a) maturation (days), (b) F_{max}
287 (N) and (c) D_{5N} (mm).
288

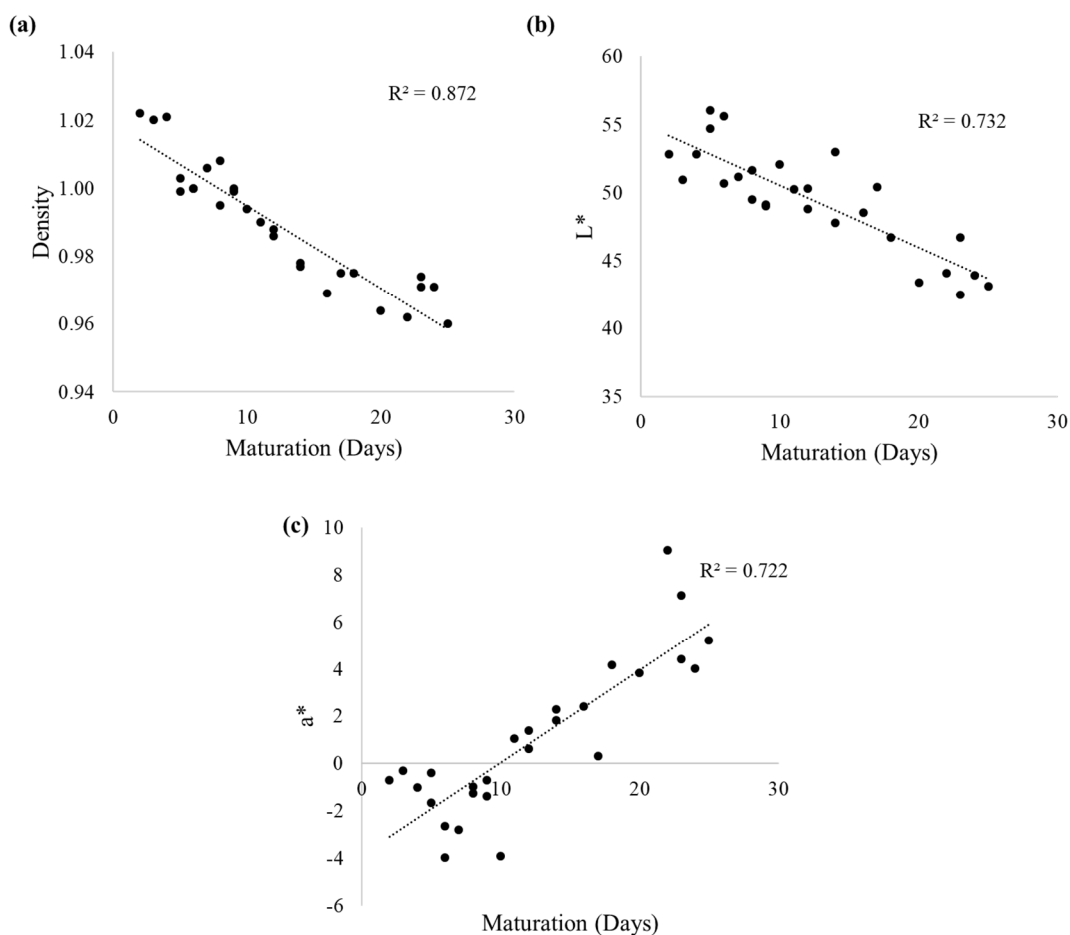
289 To sum up, both penetrometry (destructive) and compression (non-destructive) tests allowed
290 to measure significant loss of mango firmness during maturation. Compression test provided
291 better information about mango firmness after 15 days of maturation **without damaging the**
292 **fruits**. Moreover, this simple and non-destructive compression test makes possible to trace
293 back the solid-like behavior (G') of mango flesh, since D_{5N} is a good indicator of the solid-
294 like behavior of mango flesh even at stages of maturation above 15 days.

295 296 3.1.3 Other physical characterization: flesh color, fruit weight and density

297 Fruit weight, density and flesh color, were measured during maturation in order to assess the
298 effect of maturation on these physical and physico-chemical characteristics of mangos
299 (Gentile et al., 2018; Lawson et al., 2019).

300 **Fruit density decreased during maturation as presented in Fig. 3(a).** A weight loss of mango
301 fruits during maturation is mentioned by Lawson et al., 2019 and explained by the loss of
302 water through the stomata and pores (Lawson et al., 2019).

303 Concerning color, the variation of three parameters L^* , a^* and b^* is generally used to monitor
304 the variation of flesh color. The decrease of the lightness L^* point up a darkening of flesh
305 during maturation due to the activity of the polyphenol oxidases forming brown pigments (Liu
306 et al., 2013). The increase of a^* and b^* reveal biochemical changes (formation of carotenoids,
307 chlorophyll degradation, etc.) during maturation (Lawson et al., 2019; Liu et al., 2013;
308 Romainum et al., 2018). In this study, the obtained results, Fig. 3 (b), (c), were similar to
309 those previously reported by many authors regarding L^* (L^* was 1.2 times lower at the end of
310 the maturation) and a^* (a^* was 7.4 times higher at the end of the maturation), but no
311 significant evolution of b^* was observed (Data not shown).



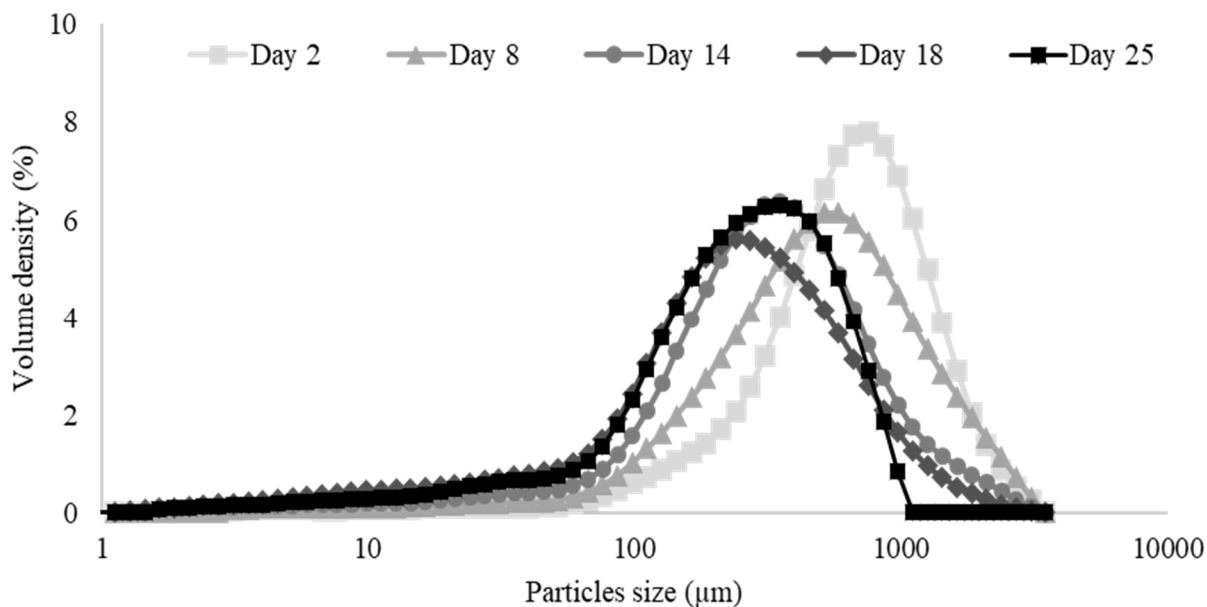
312 **Fig. 3. Evolution of (a) density, (b) and (c) L^* and a^* (color parameters) during maturation (days).**
313

314 3.2 Mango puree characterization and relations with fresh mangos characterization

3.2.1 Particles size of suspended insoluble solids

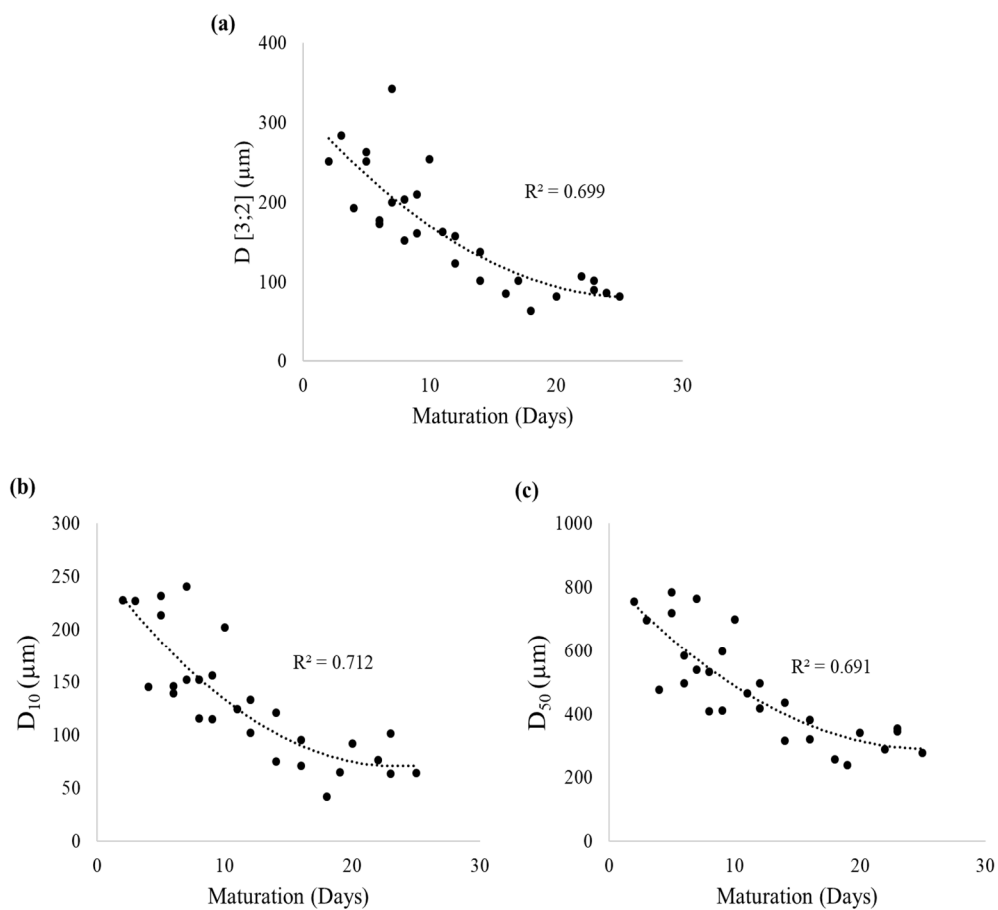
315
316 Fruit suspensions consist in two phases: a serum phase containing soluble compounds such as
317 sugars, acids and soluble pectins and insoluble phase containing insoluble suspended solids
318 such as pectins, fibers and cell walls fragments (Lopez-Sanchez et al., 2012). For fruits-based
319 suspensions, it is well known that the concentration and the size of insoluble suspended solids
320 have a major role in the structural and rheological characteristics of these products (Dahdouh
321 et al., 2016). Therefore, particles size measurements were performed on mango purees to
322 assess the size distribution of their suspended insoluble solids in relation with mango
323 maturation stage and puree rheological properties. Fig. 4 presents examples of particles size
324 distributions for mango purees at 5 different days of maturation. These distributions are
325 typical of polydisperse suspensions with a monomodal size distribution as reported in the
326 literature for many fruits suspensions such as apple purees and fruit juices (Dahdouh et al.,
327 2016; Leverrier et al., 2016). It can be noticed that purees obtained from the greenest stage
328 were characterized by the higher volume density for particles around 1000 μm . The volume
329 density of these particles larger than 1000 μm decreased considerably as the stage of
330 maturation increased to disappear in late stage of maturation. For purees obtained from mango
331 beyond 10 days of maturation, the highest volume density for particles shifted from 1000 μm
332 to 200 μm . Changes in particles size in purees in relation with mango maturation were also
333 highlighted by the evolution of the statistical diameters as they all decreased significantly with
334 maturation, Fig. 5 show some examples of the evolution of D_{10} , D_{50} and $D [3;2]$ during
335 maturation. Results concerning D_{90} and $D [4;3]$ were not depicted in this section as they
336 provided redundant information, they will be presented only in the statistical analyses.

337 This observation could be explained by the hydrolysis and degradation, during maturation, of
338 large insoluble suspended solids (starch, pectins and cell walls) into smaller compounds
339 leading to a decrease of the size of suspended insoluble particles (Venkatesan and Tamilmani,
340 2013). These results show that the loss of mango firmness and the hydrolysis of specific
341 compounds (e.g. cell walls) during the maturation could lead to mango purees with smaller
342 particles size.



343

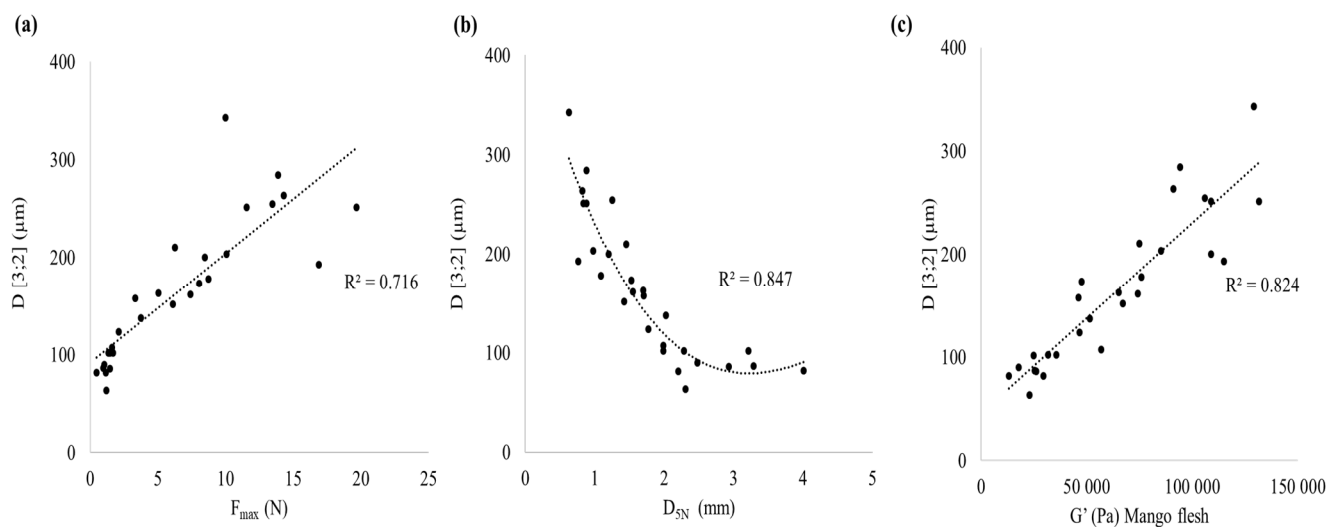
344 Fig. 4. Particles size distributions of mango purees at 5 different days of maturation.



345
346

Fig 5. Effect of maturation on (a) $D [3;2]$ (μm), (b) D_{10} (μm) and (c) D_{50} (μm).

347 Indeed, Fig. 6 (a), (b) point up significant correlations between the average surface diameter
 348 $D [3;2]$ of the purees and the firmness of mango flesh (F_{max}) and the whole fruit (D_{5N}). These
 349 observations emphasize the impact of mango firmness on the particles size distribution of the
 350 puree. Moreover, the same trend is observed between the average surface diameter $D [3;2]$
 351 and the storage modulus G' of mango flesh on Fig. 6 (c), showing that particles size
 352 distribution of mango puree is closely dependent on the solid-like behavior of mango flesh. In
 353 fact, purees grinded from the greenest mangos with a higher storage modulus G' of the flesh
 354 presented purees with larger particles. Since it is well known that grinding conditions have an
 355 important impact on the particles size distribution of purees (Espinosa et al., 2011),
 356 standardized conditions of grinding were carefully used in this work, for all stages of
 357 maturation, allowing to show the specific role of mango firmness and solid-like behavior on
 358 the particles size of the purees. Hence, this work proposes for the first time a simple and fast
 359 tool to predict the particles size of mango purees (obtained in specific conditions) based on a
 360 non-destructive compression test (D_{5N}), since the same trends were observed when destructive
 361 texture and rheological analyses were performed.



362
 363 **Fig. 6. Variation of the average surface diameter $D [3;2]$ (μm) with (a) F_{max} (N), (b) D_{5N} (mm) and (c) G' of**
 364 **mango flesh (Pa).**

365 3.2.2 Rheological characterization

366 3.2.2.1 Rotational measurements

367 The effect of maturation on the flow behavior of mango purees was investigated throughout
 368 the measurements of the viscosity of different mango purees. Several published studies,
 369 reported that fruits purees are characterized by shear-thinning behavior as their viscosity
 370 decreases with the increase of the shear rate (Espinosa-muñoz et al., 2013; Gundurao et al.,

2011; Phaokuntha et al., 2014). Since all mango purees had also shear-thinning behavior in this study, a power Law (specific of this behavior) was used to determine the consistency index (K , Pa.sⁿ) and the flow behavior index (n) of each puree (with significant determination coefficient R^2 , for $\alpha = 5\%$, degree of freedom = 27), Eq. (3):

$$\text{Power Law: } \mu_{mod} = K\dot{\gamma}^{n-1} \quad (3)$$

Where, μ_{mod} , the modeled viscosity (Pa.s), K , the consistency index (Pa.sⁿ), n , the flow behavior index and $\dot{\gamma}$ the shear rate (s⁻¹).

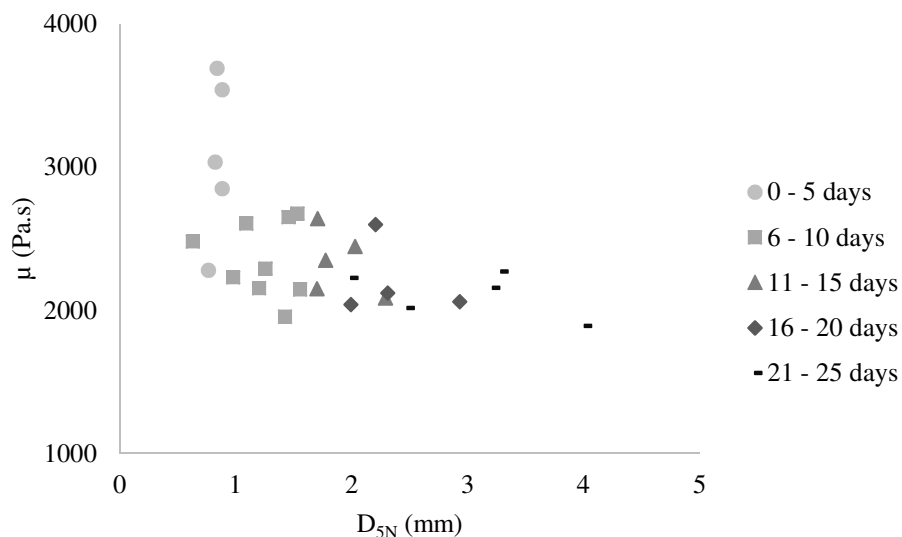
Table 1 summarize the ranges of variation of K , n and μ the experimental viscosity at 50 s⁻¹ of mango purees at different stages of maturity. To ensure the clarity of results concerning rheological properties of purees, authors presented results according to 5 stages of maturity, *a priori* ([0-5 days], [6-10 days], [11-15 days], [16-20 days], [21-25 days]). As expected, shear-thinning behavior of all purees was confirmed by the flow behavior indexes as they presented all values below 1 ($n < 1$). It can be noticed that the flow behavior indexes (n) decreased clearly as the maturation stage of mango increased whereas the consistency indexes (K) and the dynamic viscosity (μ) noticeably decreased only when comparing purees at very early and other stages of maturation. Indeed, consistency indexes were higher when considering purees at maturity stage between 0 and 5 days and slightly decreased for the other maturation stages. All these results highlight the effect of the fresh mango maturation on its puree's viscosity. This is in line with the hydrolysis of protopectins, a binding substance between cell walls and the degradation of starch, etc. (Sánchez-gimeno, 2009) occurring during maturation and inducing a decrease of the size of suspended insoluble particles, thus, leading to a decrease of the viscosity of mango puree (Espinosa et al., 2011).

Maturity stages (Days)	Range of variation of the flow index n	Range of variation of the consistency index K (Pa.s ⁿ)	Range of variation of the viscosity μ (Pa.s)
0 - 5	0.08 - 0.14	77 - 140	2.28 - 3.69
6 - 10	0.08 - 0.11	81 - 118	1.95 - 2.67
11 - 15	0.07 - 0.13	75 - 105	2.08 - 2.44
16 - 20	0.05 - 0.08	77 - 94	2.04 - 2.60
21 - 25	0.04 - 0.07	73 - 83	1.78 - 2.24

*For all data the given are the average of three trials and all standard deviation values are inferior to 5% of the average value.

Table 1. The ranges of variation of K , the consistency index (Pa.sⁿ), n , the flow behavior index and μ (Pa.s) the experimental dynamic viscosity at 50 s⁻¹ of mango purees.

398 Fig. 7 point up a decreasing trend between the experimental dynamic viscosity at 50 s^{-1} (μ) of
 399 mango puree and the firmness of the whole fruit (D_{5N}) mainly when comparing early
 400 maturation stages [0-5 days] and [6-10 days] with the other stages. This observation
 401 emphasizes the impact of mango firmness at early stages of maturation not only on particles
 402 size of purees but also on their viscosity even if the correlation between μ and D_{5N} is not as
 403 good as for D [3;2].



404

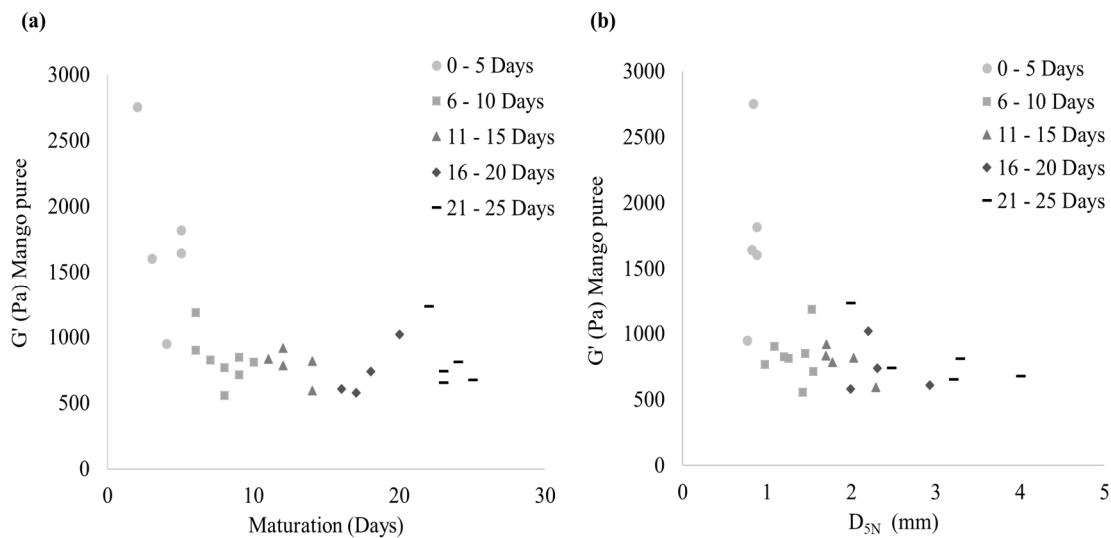
405 Fig. 7. Variation of the experimental dynamic viscosity μ at 50 s^{-1} (Pa. s) as function of the D_{5N} (mm).

406 3.2.2.2 Oscillatory Strain Sweep

407 The viscoelastic behavior of different mango purees was evaluated through an oscillatory
 408 strain sweep test. For all purees the storage modulus G' and the loss modulus G'' were
 409 constant in the domain of low strain amplitude ($< 1\%$) and characterized a linear viscoelastic
 410 region (LVE-R). In this region, the storage modulus was higher than the loss modulus,
 411 showing a viscoelastic solid-like behavior. This behavior was independent of the maturity
 412 stage since all purees showed similar trends. G' and G'' values declined and when a specific
 413 strain was reached, G'' exceeded G' indicating a transition from a solid-like ($G' > G''$) to a
 414 viscous-like ($G'' > G'$) behavior and a dependency of the rheological properties of purees on
 415 the strain. These results showed that, all purees can be considered as viscoelastic solids in the
 416 domain of low strain amplitude ($< 1\%$) and viscoelastic liquids for higher strain amplitude.

417 Although, all purees showed a viscoelastic solid-like behavior, a decrease in the storage
 418 modulus G' within the linear viscoelastic region (LVE-R) with maturity was observed
 419 indicating a significant decrease of the solid-like behavior of mango purees during maturation
 420 (Fig. 8 (a)). Indeed, the storage modulus of mango purees decreased significantly by 70%

421 before 15 days of maturation whereas beyond this maturation stage, G' was almost steady.
 422 These results show a decrease of the solid-like behavior of mango purees during maturation
 423 which is consistent with the loss of mango firmness (D_{5N} , F_{max}) and the loss of flesh solid-like
 424 behavior (G'). This observation **highlights** that the loss of mango firmness has an impact on
 425 the viscoelastic properties of the mango puree.



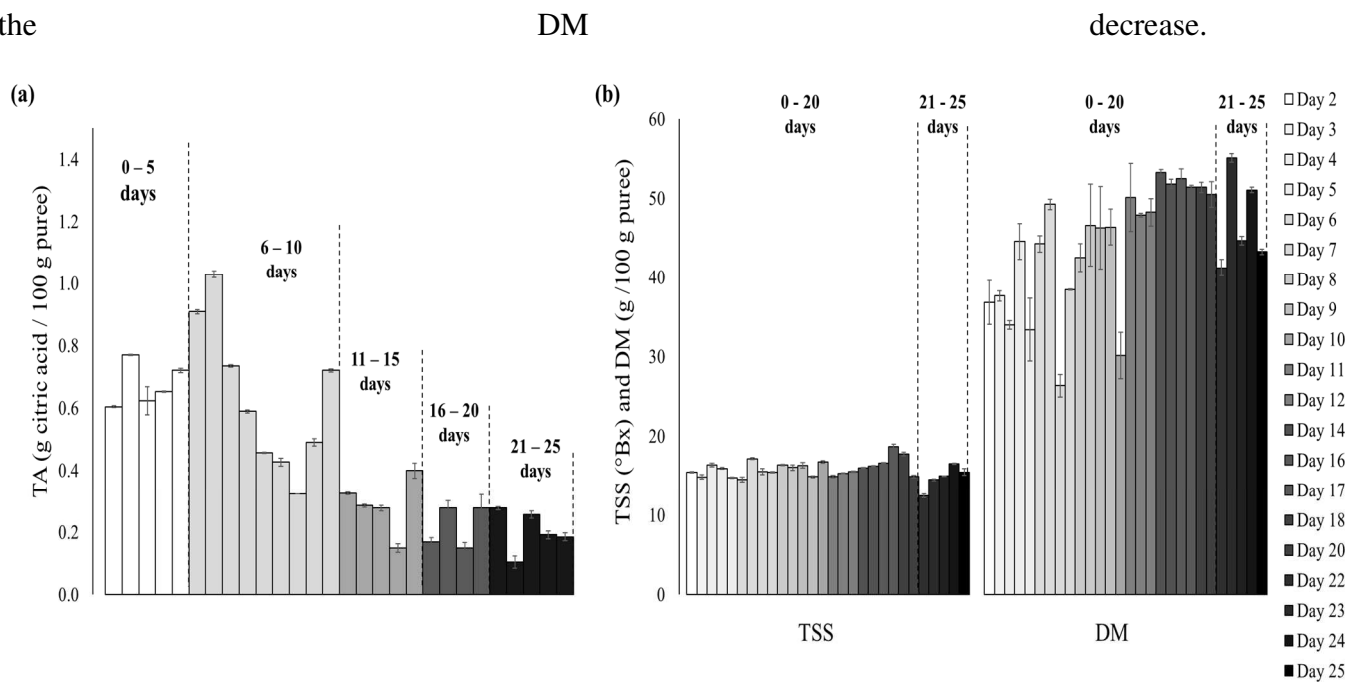
426
 427 **Fig. 8. Evolution of the storage modulus G' (Pa) as function of (a) the maturation (days) and (b) the D_{5N} (mm).**
 428

429 As for viscosity, Fig. 8 (b) shows a similar decreasing trend between for the solid-like
 430 behavior of mango puree (G') and the firmness of the whole fruit (D_{5N}), mainly when
 431 comparing early maturation stages [0-5 days] and [6-10 days] with the other stages. This
 432 observation confirmed the impact of mango firmness at early stages of maturation on the
 433 rheological properties of mango puree.

434 3.2.3 Physico-chemical analyses

435 Several physico-chemical characteristics of mango purees **were assessed** during maturation. In
 436 this study, the titratable acidity (TA, g citric acid/100g of puree) of mango purees decreased
 437 overall during maturation. Indeed, TA values were significantly higher for mangos in stages
 438 [0-5 days] and [6-10 days] than for the other stages as presented in Fig. 9. This decrease is in
 439 accordance with literature and could be explained by metabolic reactions including respiration
 440 in which organic acids are used as substrates (Gill et al., 2017; Lawson et al., 2019). After 15
 441 days of maturation, no significant decrease of titratable acidity was observed showing that no
 442 more significant degradation of organic acids occurred after this maturation stage. Concerning
 443 TSS and DM of purees, no significant changes regarding these parameters were noticed
 444 before 20 days of maturation as presented in Fig. 9 (b). This observation is not in accordance

445 with literature since several studies showed an increase in sugar content (hydrolysis of starch)
 446 and dry matter (loss in water) during maturation (Dea et al., 2013; Elbandy et al., 2014;
 447 Maldonado-Celis et al., 2019; Palafox-Carlos et al., 2012). This result could be explained by
 448 the fact that, in this study, TSS and DM of mango purees reached their highest values even at
 449 green stages [0-5 days], showing that these two parameters have evolved during storage of
 450 mango before purchasing (mango have been stored at 10°C before purchasing). Indeed, for
 451 this mango variety (*Mangifera indica* cv. Kent), several works reported that the highest values
 452 of TSS are around 20° Bx (Jha et al., 2007). After 20 days of maturation, DM and TSS
 453 decreased significantly, highlighting the degradation of sugars. These observations could be
 454 explained by the fermentation phenomenon occurring at very late stages of maturation (after
 455 20 days) during which the sugars are consumed and **volatile compounds** are generated.
 456 Moreover, the evaporation of volatile compounds (ethanol) during fermentation could explain
 457 the



458 Fig. 9. Variation of (a) the titratable acidity, TA (g citric acid / 100g puree) and (b) the total soluble solids, TSS
 459 (°Bx) and dry matter, DM (g / 100g puree) during maturation.

460

461 3.2.4 Fresh mango heterogeneity and purees characteristics

462 Principal Component Analysis (PCA) was performed in order to visualize the total variability
 463 of characteristics of fresh mangos and mango purees.

464 As presented in Fig. 10 (a), about 80% of the variation in the data related to fresh mango was
 465 explained by the first two components PC 1 (64.43%) and PC 2 (15%). PC 1 is positively
 466 correlated with L*, F_{max} and G' of mango flesh and negatively correlated with D_{5N} of mango.
 467

468 The second component (PC 2) is negatively correlated with the weight, density and b^* and
469 positively correlated with the G' of the mango flesh.

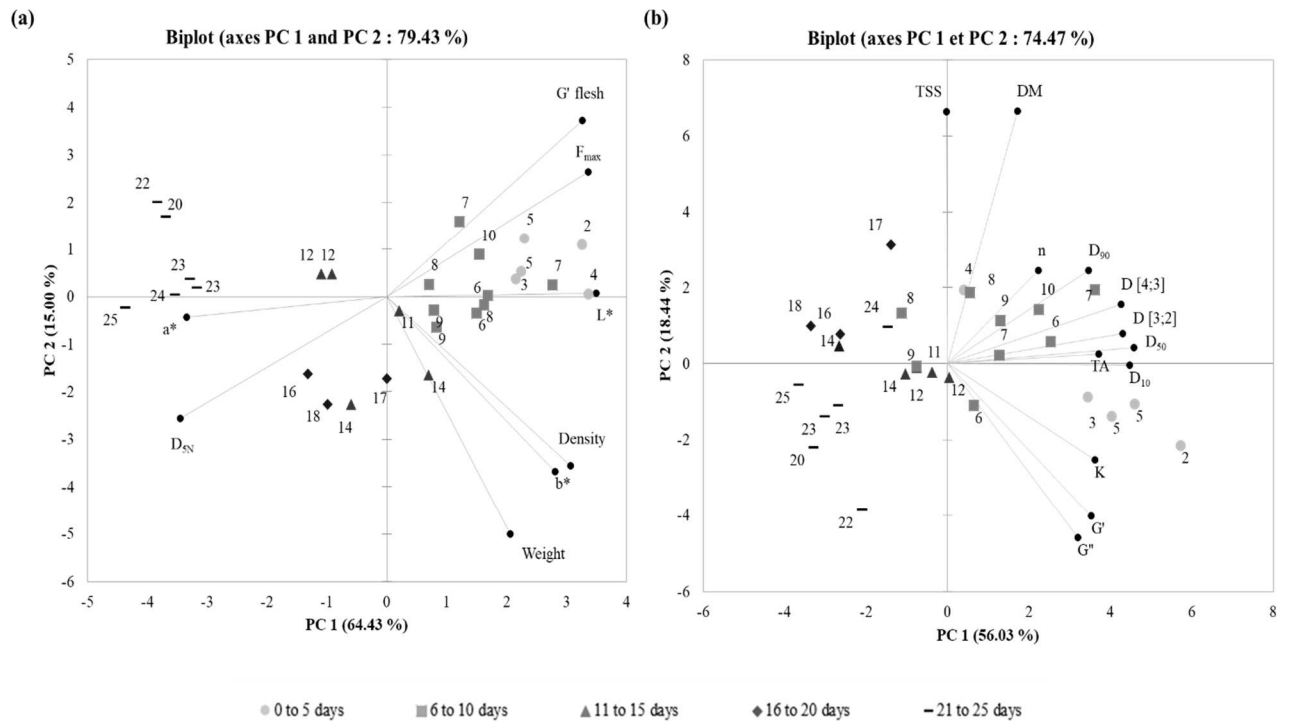
470 The projection of the 28 mangos on component PC 1 of the PCA confirmed that mangos at
471 maturation stages below 10 days (right side of the PC 1) were mainly characterized by higher
472 values of G' , F_{max} and L^* and lower values of D_{5N} and a^* which is in accordance with the
473 previous results where green mangos presented high firmness and solid-like behavior as well
474 as lighten flesh color (Fig 10 (a)). Contrariwise, the PCA highlighted that mangos at very late
475 maturation stage (above 20 days) were mainly characterized by the highest D_{5N} and a^* values
476 and low F_{max} , G' and L^* values confirming their loss of firmness and solid-like behavior and
477 their darker color. Concerning intermediate stages of maturation (between 10 and 20 days),
478 they were concentrated on the center of the biplot. No further trends are noticeable when
479 considering PC 2 information.

480 As shown in Fig. 10 (b), about 79% of the variation in the data related to mango purees was
481 explained by the first two components PC 1 (59.31%) and PC 2 (19.59%). PC 1 is positively
482 correlated with the particles size distribution, titratable acidity (TA) and rheological behavior
483 of mango purees. Indeed, statistical diameters provided 54% whereas TA, G' and K
484 contributed only to 9% each of the PC 1 information. The second component (PC 2) is
485 positively correlated with the TSS and DM (65% of PC 2 information) and negatively with
486 the G'' (12.6% information of PC 2).

487 The projection of the 28 purees onto component PC 1 of the PCA allowed to distinguish
488 purees from mangos at very early maturation stage (below 5 days) due to their highest values
489 of $D [3;2]$, $D [4;3]$, D_{10} , D_{50} , D_{90} , TA and G' . These observations are in line with the previous
490 results showing that green stages mango purees were characterized by the highest particles
491 size, titratable acidity and solid-like behavior of purees Fig. 10(b). As for PC 2 component,
492 the projection of the 28 purees enabled to discriminate purees from mango at very late
493 maturation stage (above 20 days) mainly characterized by the lowest TSS and DM. It should
494 be noticed that neither the projection on PC 1 nor on PC 2 allowed discriminating clearly the
495 other stages of maturation (between 5 and 20 days).

496 To sum up, the studied variables for fresh mangos and mango purees allowed discriminating
497 in both cases fresh mangos and mango purees into 3 main groups according to their
498 maturation stages: early, intermediate and late maturation stage. In this study, mangos at early
499 stages of maturation could be distinguished by their high firmness, solid-like behavior,

500 viscosity and particles size whereas mangos at very late maturation stage are mainly
 501 characterized by low values of total soluble solids and dry matter. Furthermore, PCA results
 502 allowed identifying relevant indicators to (i) characterize the heterogeneity of fresh mangos
 503 and mango purees and (ii) discriminate these products according to their stage of maturation.
 504 Finally, results of PCA confirmed the main trends obtained previously when considering the
 505 evolution of each variable separately as function of maturation.



506
 507 **Fig. 10. Principal component analysis (PCA) on instrumental indicators of (a) mangos and (b) purees at**
 508 **different maturity stages. a*:** red to green transition , **b*:** blue to yellow transition, **DM:** dry matter (g / 100 g
 509 puree), **D_{5N}:** distance of compression at 5N (mm), **D [3;2]:** Sauter mean diameter (μm), **D [4,3]:** Brouckere mean
 510 diameter (μm), **D₁₀, D₅₀ and D₉₀:** particle size statistical diameters (μm), **F_{max}:** maximum value of the peak force
 511 (N) , **G':** storage modulus (Pa), **G'':** loss modulus (Pa), **K:** consistency index (Pa.sⁿ), **L*:** lightness (black to
 512 white transition), **n:** flow behavior index, **TA:** titratable acidity (g citric acid/ 100 g puree), **TSS:** total soluble
 513 solids (°Bx).

514 4. Conclusion

515 The aim of this study consisted in developing innovative tools for sorting mangos according
 516 to their maturity stages and to the specific properties of their purees. Instrumental
 517 characterization of fresh mangos and mango purees were carried out to identify relevant
 518 indicators of mangos heterogeneity and purees variability. Results showed that mango
 519 firmness is a great indicator of mango maturity and has an important impact on the properties

520 of mango purees. In this work, a non-destructive compression test was proposed to measure
521 accurately the loss of mango firmness during maturation without damaging the fruits. This
522 fast and easy measurement allowed also to trace-back the solid-like behavior of mango
523 measured by destructive rheological analysis. In addition, results indicated that the firmness
524 of fresh mangos governed the particles size distributions and the rheological properties of
525 mango purees. According to these observations, it was possible to predict the particles size of
526 the mango purees based on the firmness of the fresh mangos. Concerning, purees rheological
527 properties (viscosity and solid- like behavior), compression test enabled discriminating mainly
528 mango purees at early stages of maturation [0-10 days] from the other stages [10-25 days].

529 PCA results confirmed that the investigated variables in this work (textural, rheological,
530 physical and physico-chemical) seem to be good indicators to characterize the heterogeneity
531 of fresh mangos and mango purees. It was possible to discriminate mango and puree into 3
532 main groups (early maturation stages, intermediate stages and a late maturation stage) based
533 mainly on total soluble solids, dry matter, firmness, particles size and rheological properties.

534 This work provided new knowledge in mango field and an innovative and simple tool to sort
535 mango according to firmness in relation with their maturity stage. This tool could be also of
536 great interest to anticipate the characteristics of mango puree according to mango firmness.
537 As the proposed compression test is fast and easy to perform, this sorting strategy could be
538 easily applied not only for mango fruits but also for many other juicy stone fruits in
539 transformation units to reduce post-harvest losses.

540

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546

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Graphical abstract

