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1 **Short informative title: Clustering of instrumental methods to characterize the texture and the**
2 **rheology of slimy okra (*Abelmoschus esculentus*) suspensions**

3 Short running title: Rheology and texture of slimy okra sauces

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14 **BRIEF ABSTRACT FOR THE GRAPHICAL ABSTRACT**

- 15
- 16 • Slimy okra suspensions are structured fluids with significant elongational properties.
 - 17 • Measuring flow and stringy properties is sufficient to characterize their rheological and
 - 18 textural properties and necessary to discriminate them according to their processing and
 - 19 formulation.
 - 20 • Rheological and textural properties are affected by formulation, drying and thermal
 - 21 processes.

21

22 **ABSTRACT**

23 Okra (*Abelmoschus esculentus*) is one of the ingredients widely used in African gastronomy because of
24 the unique slimy texture it gives to sauces. However, processing and formulation can affect the textural
25 and rheological properties of these sauces, leading to unacceptable quality for the African consumer.
26 The aim of this study was to select the instrumental measurements best enabling i) characterization
27 of the rheology and texture of slimy sauces prepared from okra and ii) monitoring its evolution during
28 the preservation process. 37 slimy suspensions (sauces and purées) were measured with 16 rheological
29 and textural parameters. A Principal Component Analysis revealed that flow consistency index K and
30 flow behavior index n were well correlated with visco-elastic, adhesive and shear thinning properties,
31 and that stringiness was well correlated with elongational, cohesive and ductile properties. These two
32 sets of measurement methods are sufficient to characterize their rheological and textural properties,
33 and necessary to discriminate them according to their process and formulation.

34 **KEYWORDS**

35 Okra, Slimy sauces, Stringiness, Structured fluid, Rheology, Texture

36 **1. INTRODUCTION**

37 Various plant-origin ingredients are traditionally used in West and Central African cuisine because of
38 the slimy consistency they give to sauces, soups and stews. This is the case of okra (*Abelmoschus*
39 *esculentus* (L.) Moench), nkui (bark of *Triumfetta pentandra* A. Rich) and dika nut kernels (*Irvingia*
40 *gabonensis* (Aubry Lecomte ex O'Rorke)) (Kouebou *et al.*, 2013; Mateus-Reguengo *et al.*, 2019;
41 Ndjouenkeu, Goycoolea, Morris, & Akingbala, 1996). For consumers in sub-Saharan Africa, one of the
42 essential functions of slimy sauces is to facilitate the swallowing of the starchy dough they are served
43 with (Owoeye, Caurie, Allagheny, & Onyezili, 1990). For them, the "slimy" properties of okra are its
44 main attribute, and therefore an essential quality criterion (Uzo & Ojiako 1980).

45 Okra sauces have never undergone rheological and textural characterization, but many studies have
46 focused on the rheological properties of okra extracts (mucilage, polysaccharides and pectins in
47 particular). In addition to their sliminess, they have original thickening, shear thinning, viscoelastic and
48 visco-elastic properties (Kontogiorgos, Margelou, Georgiadis, & Ritzoulis, 2012; Ndjouenkeu *et al.*,
49 1996; Sengkhamparn *et al.*, 2010), emulsifying properties (Kpodo *et al.*, 2018) and elongational
50 properties (Yuan, Ritzoulis, & Chen, 2018) properties. The rheological properties of okra mucilage are
51 the result of complex interactions between the various macromolecular populations of which it is
52 composed (Ritzoulis, 2017), including very specific pectic compounds (Kpodo *et al.*, 2018).

53 The textural properties of okra products, including sauces, can be significantly altered by preparation
54 and stabilization processes. Studies that investigated the impact of the process on the textural

55 properties of okra focused on the viscosity (simple, kinematic, relative) of its mucilage or okra sauces.
56 They showed that the viscous properties of the product are degraded by drying (Falade & Omojola,
57 2010; Inyang & Ike, 1998), blanching (Inyang & Ike, 1998) and cooking (Woolfe, Chaplin, & Otchere,
58 1977). These effects on the rheological properties of okra are a major obstacle to the conservation of
59 this vegetable before consumption in West Africa. In order to improve the processing conditions of
60 this vegetable, it is therefore essential to have tools that allow the best enabling assessment of its
61 slimy properties.

62 Only a few old studies took an interest in the instrumental measurement of the slimy texture of food.
63 For Uzo & Ojiako (1980), the perception of the sliminess of a whole okra is correlated with the
64 kinematic viscosity of its mucilage. Other authors have shown correlations between the perception of
65 sliminess in the mouth and the shear thinning (Szczesniak & Farkas, 1962; Wood, 1974) or viscous
66 properties (Richardson *et al.*, 1989) of a food, while some did not find a correlation (Terpstra *et al.*,
67 2009). As a result, no clear and consistent trend emerges from these sometimes contradictory results.
68 Moreover, measurements of viscous properties alone do not seem sufficient to appraise the quality of
69 slimy sauces, since African consumers base their assessment on their ability to elongate it (Fasogbon,
70 Taiwo, & Adeniran, 2017; Leakey *et al.*, 2005). Finally, for Szczesniak & Farkas (1962), "*a slimy material*
71 *was defined as one that is thick, coats the mouth, and is difficult to swallow*". But this definition seems
72 to contradict the fact that for African consumers, slimy sauces facilitate swallowing.

73 In this context, the objective of this study is to select the instrumental measurements best enabling i)
74 characterization of the texture of slimy sauces prepared from okra and ii) monitoring its evolution
75 during the preservation process. The proposed strategy was to measure the rheological and textural
76 properties of a wide range of samples of okra purées and sauces using different experimental methods
77 described in the literature. These methods were then compared with each other to extract the most
78 relevant instrumental parameters.

79 **2. MATERIALS AND METHODS**

80 **2.1. Sample generation**

81 In order to obtain slimy suspensions with the greatest possible variety of rheological and textural
82 properties, 37 samples were prepared by varying the formulation and using processes known to have
83 an impact on the texture of okra (Figure 1).

84 Two batches of fresh okra purée were prepared and frozen. Of these, 36 samples were formulated at
85 different pH and dry matter contents (no.1-31), mixed with other slimy ingredients (no.32-33) or used
86 in a traditional recipe (no.34-36). These preparations could then be cooked (no.5-22; no.33-37) or
87 sterilized (no.23-31). A 37th sample was obtained by cooking dried okra (no.37). Table 1 summarizes
88 the formulations and processes undergone by each of the 37 samples. In some cases, the prepared
89 samples were frozen a second time for the sake of convenience of the organization of the experiments.

90 **2.1.1. Preparation of blanched okra purées**

91 Whole fresh okras were purchased locally (Grand Frais and Paris Store, Montpellier, France). They were
92 first steam blanched at 90°C for 7 minutes. After manual removal of seeds and stalks, the okras were
93 ground with water (water/gumbo ratio = ¼; Stephan UMC5, Hameln, Germany, 2007). Given the
94 foaming properties of the product, this operation was performed at 35°C at a reduced pressure of 200
95 mbar. The resulting purées were vacuum-packed in polyethylene bags at 100 mbar (Multivac C200,
96 Wolfertschwenden, Germany, 2009), frozen and stored at -18°C. Before use, the purées were thawed
97 for 1 hour at 30°C.

98 Two batches of blanched okra purées were prepared from 10 and 20 kg of fresh okra, independently
99 of each other (8.1 and 7.8% dry matter and pH of 6.1 and 6.4 respectively). These blanched okra purées
100 were then used to prepare all samples except samples 31 and 37.

101 **2.1.2. Preparation of standardized okra purées**

102 From the blanched okra purée, samples 1 to 4 were prepared by adjusting the water content with
103 distilled water, and pH by adding a 20% sodium carbonate solution (table 1).

104 **2.1.3. Preparation of cooked okra purées**

105 From blanched okra purée, 15 samples (no.5-19) were formulated according to a three-factor Doehlert
106 experimental design (Doehlert, 1970). The pH varied from 4 to 8 (addition of citric acid solution at 0.3
107 g·mL⁻¹ or sodium carbonate solution at 20 g·mL⁻¹), the water content from 12 to 18 kg·kg_{DM} (addition
108 of distilled water) and the Ca²⁺ ion content from 0 to 4.8 g_{Ca²⁺}·kg_{DM} (addition of calcium chloride to 7
109 g·mL⁻¹). To complete the design of experiments, 3 other formulations were also chosen (samples 20-
110 22). After packaging in 370 mL glass jars, all these purées were then cooked at 70 or 85°C for 20 mins
111 in a water bath and cooled in a bath of melting ice for 30 mins.

112 **2.1.4. Preparation of sterilized okra purées**

113 Eight Sterilized okra purées (no.23-30) were prepared in the laboratory by varying the pH, water and
114 calcium contents in the same way as for cooked okra purées. Various sterilization treatments were
115 tested to cover the range of sterilization values conventionally used for canned vegetables (2.5 < F₀ <
116 10 min). After formulation, the purées were packaged in 106 mL glass jars. They were preheated in a
117 water bath at 70 °C for 20 mins and then sterilized in an autoclave (SANOclav KL-71, Wolf, Geislingen,
118 Germany, 1985). The core temperature of the vials was recorded every 20 s during processing using
119 an on-board probe held in position in their geometric centre (PicoVACQ, TMI-Orion, Castelnau-le-Lez,
120 France).

121 A complementary test was carried out at pilot scale on unblanched okra and that were ground with
122 their seeds (no.31). In this case, the product was packaged in tin-plated steel cans (390 g) and sterilized
123 in a semi-industrial autoclave (118L, Type 50, Auriol, Marmande, France, 1990). The core temperature
124 was measured every 20 seconds with a probe placed in the geometric centre of the box. The water
125 content of the sterilized purée was 11.3 (kg/kg dry matter), but it was readjusted according to Table 1
126 before rheological and textural measurements were made.

127 The sterilization value F₀ (mins) was conventionally calculated from core temperature measurements
128 T (°C) as a function of time t (mins) by numerical integration of the Bigelow formula.

129 **2.1.5. Preparation of Okra sauces**

130 Based on a traditional Cameroonian recipe for okra sauce, three samples (no.34-36) were prepared
131 using the following ingredients: fresh okra 46.9% (w/w), water 39.4%, onions 8.4%, sunflower oil 3.5%,
132 garlic 1.0%, salt 0.5% and 0.3% of a traditionally called "potash". This "traditional alkaline salt" is known
133 to have an improving effect on the texture of sauces made with okra or nkui (Ngoualem, Nguimbou, &
134 Ndjouenkeu, 2019). The "potash" used contained 170.6g/kg sodium, 42.6g/kg potassium, 14.0g/kg
135 calcium and 4.1 g/kg magnesium and had a high alkalizing power (3.69 meq·kg⁻¹). The whole
136 preparation was cooked for 15 minutes at 70°C.

137 Two other sauces were prepared with slimy ingredients to boost the textural properties of Blanched
138 okra purées. Sample no.32 was prepared by mixing 28% (w/w) nkui suspension, 29% water and 44%
139 fresh okra purée. The nkui suspension used (dry matter content 1.3%) was obtained by decoction of
140 frozen *Triumfetta pentandra* bark (JDC Africa, Paris) in boiling water for 10 mins (0.2 kg·kg⁻¹) which
141 was then stirred for 5 mins with a mixer equipped with a beater (RM8, Robot Coupe, Montceau-en-

142 Bourgogne, France) before being sieved (1mm screen). Sample no.33 was obtained by adding an
143 ogbono suspension to blanched okra purée in the proportions (0.5 kg·kg⁻¹). This ogbono suspension
144 had previously been obtained from dika nut kernels (*Irvingia gabonensis*) (Merveilles d'Afrique, Paris,
145 France), dried, ground and cooked in water for 30 mins (0.09 kg almond powder/kg water).

146 Finally, sample no.37 was prepared with dried okra from Mali (Ben Produits Exotiques, Paris, France).
147 The okra was rehydrated and cooked in water at 85°C for 10 mins. Before being readjusted for
148 rheological and textural measurements according to Table 1, the water content of the sample was 11.0
149 kg/kg (dry matter).

150 After preparation, with the exception of sample no.31, all these samples were vacuum-packaged in
151 polyethylene bags and then, for the most part, frozen at -18°C.

152 For the remainder of the article, the term suspension will be used to refer to all samples (purées and
153 sauces) used in this work.

154 2.2. Instrumental measurement methods

155 2.2.1. Physico-chemical measurements

156 The water content was determined by drying at 105°C for 24 hours and is expressed in kg/kg of dry
157 matter (DM). The pH was measured using a TitroLine® 5000 pH meter (SI Analytics, Weilheim,
158 Germany, 2017). The density of samples no.5 to 19 was evaluated by measuring the mass of a known
159 volume of sample. Each pH, water content and density measurement was performed in triplicate.

160 2.2.2. Textural characterization

161 The operating conditions under which the Texture Analyser was used to perform penetration and
162 stretching texture measurements are summarized in Table 2. Penetration measurements (firmness
163 and adhesiveness) were performed in triplicate.

164 The experimental device used to measure the stringy nature is adapted from (Gilbert, Savary, Grisel,
165 & Picard, 2013), and is described Figure 2. In order to avoid the test to be affected by surface
166 heterogeneities and to guarantee the contact between the probe and the suspensions, the probe
167 penetrated slightly inside (2 mm << depth of the steel cylinder) before stretching. After the recording
168 of the stretching test with a camera, the software VLC media player was used to extract the image
169 corresponding to the maximum filament breaking length prior to rupture. Then the length of the
170 filament was measured with the software imageJ. Each measurement was repeated 15 times. The
171 stringiness is the average of the 15 measurements.

172 2.2.3. Rheological characterization

173 The operating conditions under which the rheometer was used to perform oscillatory and steady shear
174 measurements are summarized in Table 2. Each sample was measured 3 to 5 times with a rheometer.
175 In order to allow a relaxation phase, the oscillatory test only started 15 minutes after the mobile was
176 immersed in the solution. The steady shear measurement followed the oscillatory shear measurement.
177 From the measurements made in oscillation strain sweep, the Rheoplus software was used to calculate
178 the strain ($\gamma_{LVEG'}$) and the stress ($\sigma_{LVEG'}$) at the boundary of the Linear Viscoelastic Region (LVR), the
179 moduli at the boundary of the LVR (LVEG', LVEG'', LVEG* and LVEtan δ), as well as the modulus $G'=G''$,
180 the strain ($\gamma_{G'=G''}$) and the stress ($\sigma_{G'=G''}$) at the cross-over point. The Flow Transition Index (FTI) was
181 calculated by dividing $\sigma_{G'=G''}$ by $\sigma_{LVEG''}$ (Corker, Ng, Poole, & García-Tuñón, 2019). From the steady shear
182 data, the apparent viscosities at 10 s⁻¹ and 100s⁻¹ were determined. The Rheoplus software was used
183 to calculate the consistency index K and the flow behavior index n using the Ostwald-de Waele
184 equation (Eq. 2).

185
$$\tau = K\dot{\gamma}^n \quad (2)$$

186 Where :

- 187 ▪ τ = shear stress (Pa)
- 188 ▪ $\dot{\gamma}$ = shear rate (s⁻¹)
- 189 ▪ K = flow consistency index (Pa.sⁿ)
- 190 ▪ n = flow behavior index

191 For the remainder of the article, the term instrumental parameters will be used to refer to all
192 variables obtained with the texturometer and the rheometer to characterize okra suspensions, which
193 are summarized in Table 2.

194 2.3. Data processing and statistics

195 Measurements made in oscillatory shear rheology were considered valid if the measured torque was
196 above the rheometer detection limit (50nNm). This was the case for all samples except sample no. 37,
197 for which oscillatory shear data were not taken into account.

198 The data were analyzed using R-3.5.1 software (R Core Team, 2018). The coefficient of variation was
199 the indicator used to assess the repeatability of our measurements for each parameter and sample. A
200 Principal Component Analysis (PCA) on the 16 rheological and textural parameter and 37 samples was
201 performed using the FactoMineR package (Lê, Josse, & Husson, 2008). A Pearson correlation matrix
202 was produced using the corrplot package v0.84 (Wei & Simko, 2017). The other graphical
203 representations were produced using the ggplot2 (Wickham, 2016), ggrepel (Slowikowski, 2018) and
204 ggpubr (Kassambara, 2018) packages.

205 The analysis of the experimental design was performed using the rsm package (Lenth, 2009). From
206 results of the Doehlert experimental design, correlations were established with a second-order
207 polynomial model (Eq. 3) to determine the effects of the main formulation parameter on textural
208 properties:

209
$$Y = a_0 + \sum_i a_i X_i + \sum_i a_{ii} X_i^2 + \sum_{ij} a_{ij} X_i X_j \quad (3)$$

210 Where Y is the response (Consistency Index K, Flow behavior index n, Stringiness), X_i is factor i (pH,
211 Water Content, ion calcium content), a₀ is the constant of the model, a_i is the linear effect of X_i, a_{ii} is
212 the quadratic effect of X_i, and a_{ij} the effect of interaction between X_i and X_j.

213 3. RESULTS AND DISCUSSION

214 3.1. Rheological and textural properties of okra suspensions

215 The wide measurement ranges of the samples (Table 2) show that the rheological and textural
216 properties of the samples are different from each other. It is possible to deduce some rheological
217 properties of the analyzed okra suspensions.

218 3.1.1. Textural properties

219 From a textural point of view, okra suspensions have more or less solid properties (45 < Firmness <260
220 mN) and adhesive properties (60 < Adhesiveness < 690 N.m). The upper boundary of the stringiness
221 parameter (9.4 cm measured for samples no.35 and 36) shows that some okra suspensions can have
222 remarkable elongational properties. This is consistent with the study of the elongational properties of
223 okra mucilage conducted by Yuan *et al.* (2018). This result also shows that it is possible to measure
224 instrumentally the stringy properties which African consumers evaluate by hand and visually.

225 3.1.2. Rheological properties

226 The LVR of all suspensions extended to a strain of $\gamma_{LVEG'} = 0.1\%$. The interval [18%; 35%] in which the
227 values of $LV\text{Etan}\delta$ (Table 2) are included, means that in the LVR, the suspensions have mechanical
228 properties of viscoelastic solids, varying in magnitude depending on the samples. However, they are
229 not real gels ($LV\text{Etan}\delta > 10\%$).

230 When the strain exceeds the threshold of $\gamma_{LVEG'} = 0.1\%$, the decrease in G' indicates that the material
231 begins to deform in a non-reversible way (i.e. yield) due to the progressive but irreversible destruction
232 of its internal structure under the effect of the strain. Some suspensions retain preponderant solid and
233 elastic properties ($G' > G''$) up to very significant strains ($\gamma_{G'=G''} = 250\%$). Others are very fragile and go
234 from solid behaviour ($G' > G''$) to liquid behaviour ($G' < G''$) at low deformations ($\gamma_{G'=G''} < 10\%$).

235 The shear stresses required to irreversibly deform okra suspensions ($\sigma_{LVEG'}$) or cause them to flow
236 ($\sigma_{G'=G''}$) vary from one sample to another (Table 2). Yield stress is a characteristic property of structured
237 fluids (Nakauma, Ishihara, Funami, & Nishinari, 2011) that can be estimated with $\sigma_{G'=G''}$ (Walls, Caines,
238 Sanchez, & Khan, 2003). The FTI is the ratio between $\sigma_{G'=G''}$ and $\sigma_{LVEG'}$ and can be used to characterize
239 how the internal structure of the suspensions breaks. The closer the FTI is to 1, the more brittle the
240 suspensions are (Corker *et al.*, 2019). On the opposite, the higher the FTI is, the more ductile the
241 material is, i.e. it has the ability to deform plastically without breaking. The FTI measurement range
242 shown in Table 2 indicates that some suspensions are not very resistant to deformation ($\text{min}_{FTI} = 17$)
243 while others are very ductile ($\text{max}_{FTI} = 380$).

244 These rheological properties, which are original for sauces, are certainly linked to the existence of
245 complex molecular structures. Observation of the curves from the oscillation strain sweep test (Figure
246 3) revealed that for the majority of samples (33/36 samples), at the end of the LVR, there was a slight
247 increase in the value of G'' , which is characteristic of a "weak strain overshoot" type behavior (Hyun,
248 Kim, Ahn, & Lee, 2002). According to Hyun *et al.* (2002) and Mezger (2006), the complex structure
249 made of polymer chains resists strain up to a certain threshold. Beyond this, the structure begins to
250 crack and friction between the different layers causes G'' to increase. When the strain reaches a new
251 threshold, G''' decreases as the structure breaks completely allowing the chains and/or
252 microstructures to align in the direction of flow. This behavior would be favored by the presence of
253 long side chains, their arrangement in space under the effect of electrostatic repulsion and the degree
254 to which they entangle with each other to form a more or less flexible structure. In the case of okra
255 suspensions, this explanation is plausible since it has been shown that okra pectins are of variable
256 length and branching, with more or less long side chains (Kpodo *et al.*, 2018) and that they can entangle
257 with each other via hydrogen, hydrophobic and calcium bonds (Ritzoulis, 2017). In fact, the samples
258 (no.8, 10, 21, 22, 24, 30 and 34) for which the weak strain overshoot behavior is the greatest (i.e.
259 $\text{max}_{G''/G''_0} > 1.1$) have fairly high pH values and their formulation has often been enriched with divalent
260 cations (Table 1). Only samples n°2, 3 and 33 have a strain thinning behaviour ($\text{max}_{G''/G''_0} = 1$) which can
261 be explained by the disentanglement of the polymer chains and their progressive alignment in the
262 direction of flow as the strain increases (Hyun *et al.*, 2002). These differences in behavior indicate that
263 the internal structures of the suspensions react differently to the increase in strain.

264 The consistency index K and the flow behavior index n are used to characterize their flow properties.
265 The measurement ranges of parameters K and n (see Table 2) are in line with those obtained on other
266 fruit and vegetable purées (Holdsworth, 1971). The fact that n is less than 1 for all samples means that
267 okra suspensions have a shear thinning behavior.

268 These results show that different instrumental methods can be used to characterize the rheological
269 and textural properties of okra suspensions. The next step is to identify instrumental parameters that

270 are necessary and sufficient to characterize and monitor the evolution of the specific rheological and
271 textural properties of these sauces as a function of their formulation and the preservation process
272 applied.

273 3.2. Repeatability of instrumental measurements

274 A significant proportion of samples have a coefficient of variation (CV) greater than 10% for most
275 measurements obtained by oscillatory shear rheology (LVEG', LVEG'', LVEG*, $G'=G''$, $\gamma_{G'=G''}$, $\sigma_{LVEG'}$, FTI
276 and $\sigma_{G'=G''}$, Figure 4). LVEtan δ is the only parameter obtained in dynamic rheology for which all the
277 points have a CV < 10% and which can therefore be considered as repeatable. This low repeatability of
278 oscillatory shear measurements comes in addition to the fact that they were not valid for one sample
279 (no. 37).

280 The median CV of the stringiness measurement is about 8% (Figure 4). For 75% of the samples, it is less
281 than 10% and less than 15% for the remaining 25%. This indicates a good level of repeatability for the
282 stringiness measurement. For parameters measured with the texturometer (firmness, stickiness) and
283 in steady shear rheology (K, n, η_{10} et η_{100}), the measured VC for almost all samples is less than 10% and
284 the median CV is less than 5%. The repeatability of these 4 parameters is therefore excellent.

285 However, we notice that for the consistency index K, a minority of samples (samples no.2, 31 and 37)
286 have a CV of close to 15%. For these samples, the repeatability of K is less good but remains at an
287 acceptable level. These samples are among the most watery and have a very low consistency index K
288 (< 30 Pa.sⁿ, Figure 5). These results may indicate that for the consistency index K, there is a limit of
289 quantification below which the measurement is less repeatable and which can lie between 30 and 50
290 Pa.sⁿ. The water content alone does not fully explain the lower repeatability of the consistency index
291 K measurements for these 3 points since sample no.32 has a CV lower than 5% while its water content
292 is high (26.3 %).

293 3.3. Reduction of the number of instrumental parameters

294 3.3.1. Correlation of instrumental parameters with each other

295 In the Figure 6, it can be seen that a 2-dimensional space allows to represent 86% of the variance
296 carried by the 16 parameters. The first dimension of the PCA (Figure 6A) is well correlated ($p < 5\%$)
297 with the parameters η_{10} ($r = 0.99$), K ($r = 0.98$), LVEG' ($r = 0.97$), LVEG* ($r = 0.97$), η_{100} ($r = 0.97$), $\sigma_{LVEG'}$ (r
298 $= 0.97$), firmness ($r = 0.95$), $\sigma_{G'=G''}$ (0.94), n ($r = -0.91$), LVEG'' ($r = 0.88$), adhesiveness ($r = 0.86$) and
299 LVEtan δ ($r = -0.77$). To a lesser extent, it is also correlated with the water content measurement ($r = -$
300 0.50). The first component of PCR can therefore be interpreted as a dimension positively correlated
301 with the viscous, elastic, shear thinning and adhesive properties of suspensions. The negative
302 correlation of the water content (supplementary variable) with the first dimension illustrates this
303 interpretation. The second dimension of the PCA is well correlated ($p < 5\%$) with the parameters $\gamma_{G'=G''}$
304 ($r = 0.89$), $G'=G''$ ($r = -0.78$), stringiness ($r = 0.75$) and FTI ($r = 0.68$). This second dimension is therefore
305 positively correlated with the ductility and stringy properties of suspensions. It certainly corresponds
306 to the cohesiveness when defined as "the extent to which a material can be deformed before it
307 ruptures" (Brenner *et al.*, 2014).

308 The meaning given to the two dimensions makes it possible to characterize the differences between
309 the types of samples. On the first dimension of Figure 6B, the "Cooked okra purées" are clearly
310 distinguishable (right) from the three other sample groups (left). On the second dimension, three
311 groups of samples can be distinguished: Sterilized okra purées (bottom), Standardized okra purées and
312 Cooked okra purées (middle) and Okra sauces (top). The study of their viscous, elastic, shear thinning
313 and adhesive properties made it possible to distinguish two groups of suspensions, while the study of
314 their ability to resist plastic deformation without breaking made it possible to distinguish three groups

315 of suspensions. Two dimensions are therefore sufficient to characterize the rheological and textural
316 properties of slimy suspensions and necessary to differentiate them. This is consistent with the
317 proposal of van Vliet (2002), for whom it is the combination of several parameters (viscosity, shear
318 rate thinning behaviour and elongational flow) that would allow a good estimate of the slimy level of
319 a solution. This result is also in line with the work of Yuan, Ritzoulis & Chen (2018) and Leakey *et al.*
320 (2005) for whom it is the combined study of the viscous and elongational properties of okra mucilage;
321 for the former, and of soups made with dika nut kernels; for the latter, that would best describe the
322 original mechanical and textural properties of these slimy ingredients. Finally, in the context of
323 research seeking to identify "gum based thickeners" with "ease of swallowing" properties, E. K. Hadde
324 & Chen (2019) have shown the interest of jointly studying these two dimensions.

325 3.3.2. Identification of the parameters best correlated with the others

326 At the top left of the *figure 7*, a group of parameters, all correlated to each other, is clearly apparent
327 ($LVEG''$, $\sigma_{LVEG'}$, $LVEG'$, $LVEG^*$, η_{10} , K , firmness, η_{100} , $\sigma_{G'=G''}$, adhesiveness, n and $LVEtan\delta$). These
328 parameters are also those that contribute significantly and strongly to the formation of the first
329 dimension of the PCA (Figure 6A). Within this group, K and n are the two repeatable measurements
330 ($CV < 10\%$, see Figure 4) that are best correlated with the other parameters. Indeed, the intensity
331 correlation of K with the other parameters of this group is between 0.77 and 0.98 while the intensity
332 correlation of n is between 0.76 and 0.88. K and n are therefore the most relevant parameters to
333 characterize the first dimension of the PCA. From a practical point of view, it is not necessary to select
334 one of these two parameters since they are measured at the same time and are complementary in
335 characterizing the flow of suspensions.

336 At the bottom right of figure 7, the parameters $\gamma_{G'=G''}$, $G'=G''$, FTI and stringiness form a second group
337 that corresponds to the second dimension of the PCA (figure 6A). Within this group, the parameters
338 $\gamma_{G'=G''}$ and stringiness are the two parameters best correlated with the other parameters since the
339 intensities of their correlations with the other parameters in this group are respectively between 0.52
340 and 0.74 and between 0.42 and 0.57. It seems more interesting to select stringiness because it is the
341 only one of these four parameters to allow a valid measurement of sample no.37 and it has a better
342 repeatability than $\gamma_{G'=G''}$, $G'=G''$ and FTI (Figure 4).

343 3.3.3. Comparison of the differentiating power of the consistency index K with the other 344 parameters of the "consistency dimension"

345 K is very well correlated with the shear thinning (Figure 8A) and viscoelastic (Figure 8B) properties of
346 okra suspensions as well as with their yield stress (Figure 8C) and firmness (Figure 8D). Since the flow
347 behavior index n is less well correlated with these parameters than with K (Figure 7) and the amplitude
348 of its measurement range is less important (Table 2), its correlations with these parameters has not
349 been plotted in order not to multiply the graphical representations.

350 In the Figure 8A and Figure 8B, we observe that compared to flow behaviour index n and $LVEtan\delta$, K
351 makes it easier to distinguish the 4 samples (no. 7, 8, 15 and 17), for which the value of K is high (> 300
352 $Pa.s^n$), from the rest of the Cooked okra purées. In Figures 6C and 6D, it can be seen that K allows a
353 better discrimination of samples with a value lower than $100 Pa.s^n$, than the parameters $\sigma_{G'=G''}$ and
354 firmness. In Figures 8C and 8D, we can see that compared to $\sigma_{G'=G''}$ and firmness, K allows to better
355 differentiate samples with a value lower than $100 Pa.s^n$. This confirms that among the parameters of
356 the first dimension, the consistency index K is the most suitable for differentiating samples from each
357 other, including for high and low values of its measuring range. However, like the other parameters of
358 the consistency dimension (Figure 6A and Figure 7), K does not allow a clear distinction between
359 samples of the Sterilized okra purées, Standardized okra purées and Okra sauces types which have
360 similar values.

361 **3.3.4. Comparison of the discriminating power of stringiness with the other parameters of**
362 **the "ductility-cohesiveness" dimension**

363 As suggested by the correlation coefficients in Figure 7, it can be seen in Figure 9 that the correlations
364 between the parameters carried by the "ductility-cohesiveness" dimension are of lower quality than
365 for the "consistency dimension" parameters (Figure 8). This is due in particular to the presence of a
366 few samples (No. 23, 28, 32, 35 and 36) for which the values obtained are very different from the lot.

367 In Figure 9A, 7/9 of Sterilized okra purées samples have a $G'=G''$ value similar to that of the Cooked
368 okra purées group. Moreover, Okra sauces and Standardized okra purées samples have comparable
369 values. In Figure 9B, the Okra sauces samples have values of $\gamma_{G'=G''}$ comparable to those of the Cooked
370 okra purées group. In Figure 9C, except for samples 32 and 33, it is not possible to distinguish between
371 Okra sauces, Standardized okra purées and Cooked okra purées samples using the measured FTI
372 values. Therefore, the parameters $G'=G''$, $\gamma_{G'=G''}$ and FTI, shown vertically in Figures 9A, 9A and 9C, do
373 not allow the sample groups to be correctly distinguished from each other. On the other hand,
374 Stringiness, represented horizontally on the 3 graphs in Figure 9, makes it possible to clearly distinguish
375 three groups of samples: Sterilized okra purées on the left, Standardized okra purées and Cooked okra
376 purées in the centre, and Okra sauces on the right. Stringiness is therefore the parameter that best
377 complements K since, unlike K (Figure 8), stringiness clearly distinguishes samples of the "Okra sauces",
378 "Sterilized okra purées" and "Standardized okra purées" types.

379 **3.3.5. Space formed by the stringiness and flow parameters to characterize the samples**

380 The two-dimensional space formed by the combination of stringiness with K or n makes it possible to
381 clearly distinguish the 37 suspensions that have been produced by varying the formulation and
382 production process of the suspensions (Figure 10A and B). With the exception of sample no.37, the
383 four types of samples form homogeneous groups and are clearly distinguishable from each other.

384 In Figure 10A and B, it can be seen that some samples have a similar flow properties but a very different
385 stringiness level (see samples no.23 and no.36 for example). This result is consistent with the work of
386 Hadde & Chen (2019) who showed that fluids could have similar properties when subjected to "shear
387 deformation" but very different properties when subjected to "extensional deformation". In Figure
388 10A and B, we can see that the opposite is also true: some samples may have similar properties when
389 subjected to "extensional deformation" but very different ones when subjected to "shear
390 deformation" (see samples no.17 and no.30 for example). The combination of flow and stringy
391 properties measurements is therefore suitable for discriminating slimy suspensions.

392 **3.4. Ability of the stringiness and flow parameters to characterize the impact of the process**
393 **and formulation on the textural properties of okra**

394 **3.4.1. Impact of the process on the textural properties of okra**

395 The graphs in Figure 11 distinguish the effects of water content and process on both stringiness and
396 suspension flow. The increase in the water content of the suspensions leads to a decrease in their
397 consistency index K (Figure 11A) and a degradation of their shear thinning properties (increase of n in
398 Figure 11B). However, its effect on stringiness is not obvious (Figure 11C).

399 Cooked okra purées and Sterilized okra purées have a similar water content (respectively between 11.9
400 and 17.9 and between 11.8 and 18.2 kg/kg dry matter, Table 1). Figure 11A, Figure 11B and Figure 11C
401 show that compared to Cooked okra purées, Sterilized okra purées have a lower consistency index K,
402 a higher flow behaviour index n and a lower stringiness level. This means that sterilization degrades
403 the consistency, shear thinning properties and elongational properties of okra suspensions. These
404 results confirm and supplement the researches of Inyang & Ike (1998) and Woolfe, Chaplin, & Otchere
405 (1977), who observed degrading effects of blanching and cooking on okra viscous properties. The

406 increase in $LV\epsilon\Delta$ induced by sterilization (data not shown) reveals that heat treatment degrades the
407 internal structure of okra suspensions. Since the degree of methylation of okra pectins is quite low
408 (<26% according to Kpodo *et al.* (2018)), this degradation is certainly the consequence of the
409 depolymerization of okra pectins by β -elimination or acid hydrolysis (Moelants, Cardinaels, Van
410 Buggenhout, *et al.*, 2014).

411 In Figure 10, it can be seen that the sample prepared from dried okra (no.37) has very different
412 characteristics from other Okra sauces samples but very similar to those of Sterilized okra purées. In
413 Figure 11, we can see that compared to samples with a close water content (n°3, 16 and 31), sample
414 n°37 is the least consistent sample and shear thinning (Figures 11A and B) and is not very stringy (Figure
415 11C). These results supplement those of Falade & Omojola (2010) and Inyang & Ike (1998) who showed
416 that the drying process had an effect on the viscosity of the dried okra. It suggests that the conditions
417 under which okra is dried in West Africa can probably be improved.

418 On the three charts in figure 11, it can be seen that the characteristics of the 35 and 36 samples are
419 identical. Freezing has no impact on the stringiness and flow characteristics of okra suspensions. This
420 confirms and supplement the results of Olorunda & Tung (1977) and Falade & Omojola (2010).

421 On the three charts in Figure 11, we can see that the Okra sauces to which other slimy ingredients have
422 been added (no.32-36) have remarkable elongational properties and this for different water content
423 levels. This means that the addition of two slimy ingredients in samples 32 and 33 increased the
424 elongational characteristics of okra suspensions. It can be seen that the three traditional recipes (no.34
425 - 36) in which other ingredients, including "potash", have been added, are the most stringy. The
426 presence of this alkaline and mineral-rich ingredient, known for its effect on okra texture (Ngoualem
427 *et al.*, 2019), certainly contributes to the high level of stringiness observed for these samples.

428 **3.4.2. Impact of the formulation on the textural properties of okra**

429 Table 3 shows that water content has a significant and dominant linear effect on all three parameters
430 and a significant quadratic effect on K and n. The pH has a significant quadratic effect on n of the same
431 order of magnitude as the linear effect of water content. The calcium ion content has a significant
432 linear effect at the 15% threshold on K and n and at the 10% threshold on n but has no effect on the
433 stringiness.

434 The linear effect of the water content on K ($a_2 = -125.7$) and n ($a_2 = 0.037$) indicates that the increase
435 in water content decreases the consistency index K of the purées and their shear thinning properties.
436 The quadratic effects of water content on K ($a_{22}=67.5$) and n ($a_{22}=0.016$) mean that these degradations
437 are less pronounced as the water content increases. This result is in line with that of Woolfe, Chaplin
438 & Otchere (1977) on okra mucilage. Other authors have observed similar effects of particle
439 concentration on other plant-tissue-based suspensions (Moelants *et al.*, 2014). Increasing the water
440 content above a certain level reduces hydrodynamic interactions between particles, which modifies
441 the flow properties of purées (Moelants *et al.*, 2014).

442 The pH has a quadratic effect on the flow behavior index n ($a_{11} = -0.032$). Its negative sign indicates the
443 presence of a maximum. Its intensity is of the same order of magnitude as that of the water content
444 ($a_2 = 0.037$), which shows that this effect is quite significant. Woolfe, Chaplin, & Otchere (1977) showed
445 relative viscosity of okra mucilage reaches and optimum when pH values are between 6 and 8. This
446 could be the consequence of the effect of pH on the spatial conformation of okra pectins, which can
447 change from a compact conformation at acidic pH to an extended one at neutral pH (Alba, Bingham,
448 & Kontogiorgos, 2017; Alba, Kasapis, & Kontogiorgos, 2015; Ritzoulis, 2017). Furthermore, Yuan *et al.*
449 (2018) showed that at pH4, within the okra mucilage, the particles were less numerous but larger than
450 at pH7, and that this imparted its viscosity. Here, it is interesting to note that the pH has been shown

451 to have a strong and significant effect on the density of okra suspensions. At acidic pH, suspensions
452 foamed (density < 1), which is in accordance with the emulsifying properties of okra pectins at acid pH
453 (Alba, Ritzoulis, Georgiadis, & Kontogiorgos, 2013). All these elements indicate that by acting on the
454 spatial conformation of okra pectins, pH modifies the properties of the matrix they form within the
455 purées, which has an effect on their flow properties.

456 The calcium ion content has a negative quadratic effect ($a_{33} = -0.014$) on n which is dominant compared
457 to its linear effect ($a_3 = 0.0052$). This means that the increase in calcium ion content causes the n
458 increase until it reaches an optimum. The other effect of the calcium ion content on the flow of the
459 purées is to reduce their consistency index K ($a_3 = -13.3$), which is consistent with the result of Woolfe,
460 Chaplin, & Otchere (1977) and Ndjouenkeu *et al.* (1996). It has been suggested that by "screening" the
461 negative charges of pectins on the surface of the particles, calcium ions facilitate the flow of purées
462 (Moelants *et al.*, 2014). This effect is thought to have a stronger impact on their rheology than the
463 gelling effect of Ca^{2+} ions on weakly methylated okra pectins.

464 The stringiness level of the purées increases linearly with their water content ($a_2 = 0.8$). Our results
465 may seem contradictory to those of Yuan *et al.*, (2018) who showed that the increase in mucilage
466 concentration resulted in an increase in break-up time (equivalent to stringiness). The difference of
467 concentration used in the two studies (between 0.25 and 3.00% vs. between 4.9 and 7.4%) can explain
468 this difference. In fact, additional experimental work has shown that stringy properties of okra reached
469 a maximum at an intermediate concentration (data not shown). The relatively high concentrations
470 used may also explain why, unlike Yuan *et al.* (2018), no significant pH effects on the elongational
471 properties of okra purées were observed.

472 Of the three factors studied, it is the water content that has a central and dominant effect on the three
473 parameters. But while increasing it degrades the consistency and shear thinning properties of purées,
474 it increases their ductility. These three parameters therefore seem to measure the same phenomenon,
475 namely the structuring or softening of the structured fluid according to its concentration of bio-
476 polymers and particles. On the micro scale, the increase in water content reduces hydrodynamic
477 interactions between particles and the ability of okra pectins to entangle to form a solid and elastic
478 structure. On a macro scale, with the increase in water content, the structure becomes more flexible
479 and its ability to resist plastic deformation without breaking increases: it becomes less fragile and more
480 ductile. While in the experimental field studied, the stringiness of suspensions is only sensitive to water
481 content, their flow properties are also sensitive to calcium ion concentration and pH. As we have
482 shown that the stringiness parameter has a better ability than the flow parameters to differentiate
483 between sample types, this confirms that it is useful to keep all three parameters to study the impact of
484 the process and formulation on the rheology and texture of okra suspensions.

485 4. CONCLUSION

486 Sixteen rheological and textural parameters were measured to characterize the texture and rheology
487 of okra slimy suspensions. These suspensions have viscoelastic, shear thinning, adhesive, stringy,
488 ductile and cohesive properties, and can be classified as structured fluids. A PCA showed that two
489 dimensions are sufficient to characterize their rheological and textural properties and necessary to
490 differentiate them. While the first dimension is correlated with their viscoelastic, shear thinning and
491 adhesive properties, the second dimension is correlated with their stringy, cohesive and ductile
492 properties. Consistency index K and flow behavior index n are two repeatable measures that are very
493 well correlated with the other 10 parameters carried by the first dimension of the PCA. Stringiness is a
494 repeatable measurement that is well correlated with the other 3 parameters of the second dimension
495 ($\gamma_{G'=G''}$, $G'=G''$ and FTI).

496 Combining the consistency index K and the stringiness is very good at differentiating the samples with
497 respect to the process and the formulation they have undergone. These instrumental parameters
498 therefore seem complementary in their ability to i) characterize the degree of structure of the slimy
499 suspensions as a function of their formulation and ii) monitor the degradation of their rheological and
500 textural properties as a result of the process. This work therefore makes it possible to find levers to
501 limit the degradation of the rheological and textural properties of okra during processing. To this end,
502 it would be helpful to study which biochemical mechanisms are involved in these degradations.

503 The fact that slimy sauces, like other slimy solutions such as hagfish slime (Böni, Fischer, Böcker, Kuster,
504 & Rühls, 2016), have remarkable stringy properties suggests that this characteristic could be related to
505 the sensory perception of the slimy texture. An adapted sensory analysis work will have to be carried
506 out in order to validate the existence of such a correlation. If this is confirmed, it will be possible to use
507 the set of measuring methods identified in this work to engineer the texture and the rheology of
508 African slimy sauces.

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513 **ETHICAL STATEMENTS**

514 The authors declare that they do not have any conflict of interest

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641 Tables legends

642 Table 1. Summary of main preparation process and formulation of the 37 samples used for rheological
643 and textural analysis

644 Table 2. Instrumental methods and parameters selected for characterizing rheological and textural
645 properties of okra suspensions

646 Table 3. Effects of pH, water content and calcium ion content on the consistency index K, the flow
647 behavior index n and the stringiness of cooked okra purées (samples n°5-19)

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651

652 Table 1 : Summary of main preparation process and formulation of the 37 samples used for
653 rheological and textural analysis

Sample Number	Name	pH	Water content (kg/kg dry matter)	Added calcium (g Ca ²⁺ /kg dry matter)	Thermal process Temperature (°C) x time (min) [F ₀ for sterilization (min)]	
1	Standardized okra purées	7.2	15.8	0		
2		7.3	25.3	0		
3		6.4	19.0	0		
4		7.1	19.5	0		
5	Cooked okra purées	6.0	14.9	2.4	70 x 20	
6		6.0	16.4	2.4		
7		4.5	11.9	2.4		
8		7.1	12.2	2.4		
9		4.6	17.2	2.4		
10		7.4	16.5	2.4		
11		4.6	14.5	0.7		
12		7.4	14.8	0.7		
13		4.6	14.9	4.1		
14		7.4	14.6	4.1		
15		6.0	12.2	0.7		
16		6.1	17.9	0.7		
17		6.0	12.0	4.1		
18		6.0	17.1	4.1		
19		6.0	14.6	2.4		
20		6.2	15.9	0		
21		7.2	15.1	4.8		
22		7.3	15.0	4.8		85 x 19
23	Sterilized okra purées	5.2	15.4	0	115 x 58 [F ₀ =5.4]	
24		5.9	16.3	0	125 x 22 [F ₀ =3.4]	
25		5.4	15.9	0	125 x 26 [F ₀ =7.3]	
26		5.7	15.8	0	120 x 35 [F ₀ =6.7]	
27		5.5	16.2	0	120 x 50 [F ₀ =9.9]	
28		4.3	12.6	3	125 x 24 [F ₀ =7.5]	
29		7.6	11.8	4.8	125 x 24 [F ₀ =8.1]	
30		6.4	15.3	4.8	125 x 21 [F ₀ =5.6]	
31		5.7	18.2	0	121 x 60 [F ₀ =4.2]	
32	Okra sauces†	With Nkui	6.6	26.3	0	
33		With Ogbono	5.8	10.1	0	80 x 30
34		Traditional recipe 1	7.7	7.1	0	70 x 15
35		Traditional recipe 2	6.5	8.8	0	70 x 15
36		Frozen traditional recipe 2	6.5	8.8	0	70 x 15
37		Dried okra sauce	6.3	18.5	0	85 x 20

†: See section 2.1.5. for further explanations about Okra sauce formulation and preparation.

654 Table 2 : Instrumental methods and parameters selected for characterizing rheological and textural
655 properties of okra suspensions

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Methods					Value range obtained with the 37 samples
Material	Type of measurement	Selected parameter	Description	References	
Anton Paar MCR 301 rheometer equipped with the starch cell C-ETD160/ST and with the measuring geometry ST24-2D/2V/2V-30 (stirrer with 3 pairs of blades)	Oscillation strain sweep test: frequency = 1 Hz; strain interval = [0.001; 1000] %; 5 measurement/strain decade; temperature = 25°C	LVEG'	Elastic modulus at the end of the Linear Viscoelastic Region	Mezger (2006) & Walls, Caines, Sanchez, & Khan (2003)	[100; 7410] Pa
		LVEG''	Viscous modulus at the end of the Linear Viscoelastic Region		[30; 1500] Pa
		LVEG*	Complex modulus at the end of the Linear Viscoelastic Region		[100; 7540] Pa
		LVEtanδ	Damping factor at the end of the Linear Viscoelastic Region		[18; 35] %
		$\gamma_{LVEG'}$	Strain at LVEG' (limit of the Linear Viscoelastic Region)		0,10%
		$\sigma_{LVEG'}$	Stress at LVEG'		[0.1 ; 7.5] Pa
		$G'=G''$	Modulus at cross-over point		[10; 940] Pa
		$\sigma_{G'=G''}$	Stress at cross-over point		[13; 470] Pa
		$\gamma_{G'=G''}$	Strain at cross-over point		[6; 250] %
		FTI	Flow Transition Index = $\sigma_{G'=G''}/\sigma_{LVEG'}$		Corker, Ng, Poole, & García-Tuñón (2019)
	Flow measurement under steady state : shear rate interval = [0.001; 1000] s ⁻¹ ; 5 measurement/shear rate decade; temperature = 25°C	K	Consistency index K calculated using the de Waele-Ostwald equation	Mezger (2006),	[3; 340] Pa.s ⁿ
		n	Flow behavior index calculated using the de Waele-Ostwald equation	Holdsworth (1971)	[0.16; 0.66]
		η_{10}	Apparent viscosity measured at 10 s ⁻¹	Sharma, Kristo, Corredig, & Duizer (2017)	[2; 50] Pa.s
		η_{100}	Apparent viscosity measured at 100 s ⁻¹		[0.6; 6] Pa.s

Stable Micro Systems TA.XT.plus Texture Analyser equipped with the same PVC cylindrical probe (diameter = 2 cm)	Penetration: The sauce was poured and tossed in a glass beaker (depth = 3 cm; diameter = 6 cm). The sample was left to relax for 2 min, before a single compression test was performed with following settings: Pre-test, test and post-test speed = 2 mm.s ⁻¹ ; trigger force = 3 g; penetration distance = 3 mm. Temperature = 25°C (±1°C)	Firmness	Maximum force measured at the end of the penetration into the product	Nishinari et al. (2019), Rosenthal (2010), Bourne (2002)	[45; 260] mN
		Adhesiveness	Area under the curve force corresponding to the work of adhesiveness while the probe is pulling up back from the sauce		[60; 690] N.m
	Stretching: The sauce was poured and tossed in a steel cylinder (diameter = 3 cm). The sample was let to relax for 2 min before that a single compression test was performed with following settings: Pre-test speed = 10 mm.s ⁻¹ , test and post-test speed = 40 mms.s ⁻¹ ; trigger force = 2 g; penetration distance = 2 mm. Temperature = 25°C (±1°C)	Stringiness	Average breaking length of the filament	Gilbert et al. (2013)	[1.2; 9.4] cm

658 Table 3: Effects of pH, water content and calcium ion content on the consistency index K, the flow
659 behavior index n and the stringiness of cooked okra purées (samples n°5-19)

Coefficient†	Consistency index K (Pa.s ⁿ)	Flow behaviour index n	Stringiness
Constant			
a ₀	203.9*****	0.216*****	3.8*****
Linear			
a ₁	4.6	0.005	0.0
a ₂	-125.7*****	0.037*****	0.8*****
a ₃	-13.3*	0.0052*	0.1
Interactions			
a ₁₂	-14.8	-0.001	-0.2
a ₁₃	19.1	0.008	-0.2
a ₂₃	-0.5	-0.005	0.0
Quadratic			
a ₁₁	-3.4	-0.032*****	-0.2
a ₂₂	67.5*****	-0.016**	0.0
a ₃₃	4.4	-0.014**	-0.1
R ²	0.9817	0.9712	0.9539
† Indices 1, 2, and 3 refer to pH, Water Content, and Calcium ion content respectively. Significance (p-value) : ***** <0.01% / ***** <1% / *** <5% / **<10% / *<15%			

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662 **Figures legends**

663 Figure 1: Production diagram of the 37 samples used for rheological and textural analyses.

664 Figure 2: Drawing of the experimental set-up for stringiness measuring

665 Figure 3: Elastic (G') and Viscous (G'') moduli of the 36 samples (measurements of the sample no.37
666 were not valid) as a function of strain at 1Hz (A and B). Reduced moduli G'/G'_0 and G''/G''_0 versus
667 strain, where G'_0 and G''_0 are the moduli measured at the beginning of the linear viscoelastic region
668 (see (Hyun et al., 2002)).

669 Figure 4: Distribution of coefficient of variation (CV) measured on the 37 samples for the 16 rheological
670 and textural parameters. The numbers indicate the samples for which an extreme CV has been
671 measured. The 10% dashed line corresponds to the threshold above which the measurement was not
672 considered repeatable.

673 Figure 5: Variation coefficient of consistency index K vs measured consistency index K. The color
674 gradient of the points corresponds to the water content (dry matter) of the measured samples. The
675 sample number is written when the measured value is less than 50 Pa.sⁿ. The 10% dashed line
676 corresponds to the threshold above which the measurement was not considered repeatable.

677 Figure 6: Principal Component Analysis (PCA) biplot of the 16 textural and rheological parameters and
678 the 36 samples. The explained variance for PC1 and PC2 is 66.61 % and 19.68 %. On the parameters
679 factor map (A), Water Content is a supplementary parameter that does not contribute to the formation
680 of the components. On the Projection of individuals (B), the number indicates samples and confidence
681 ellipses were traced around the samples categories.

682 Figure 7: Pearson correlation coefficients matrix of the 16 parameters. The lower left half shows the
683 Pearson correlation coefficients significant at the 5% threshold. The upper right half shows the
684 graphical representation of these coefficients: their color depends on the sign of the correlation while
685 the size of the disks and the intensity of the color represent the intensity of the correlation.

686 Figure 8: Graphical illustrations of the correlation between the consistency index K and the main
687 rheological and textural properties of the first dimension of the PCA: flow behavior index n (A), $LVEtan\delta$
688 (B), $\sigma_{G'=G''}$ (C) and firmness (D).

689 Figure 9: Graphical illustrations of the correlation between stringiness and the main rheological and
690 textural properties of the second dimension of the PCA: $\gamma_{G'=G''}$ (A), $G'=G''$ (B), FTI (C).

691 Figure 10: The two-dimensional space formed by stringiness in combination with the consistency index
692 K (A) and the flow behavior index n (B).

693 Figure 11: Water-dependence of flow consistency index K (A), flow behaviour index n (B) and
694 stringiness (C) for the 37 suspensions.

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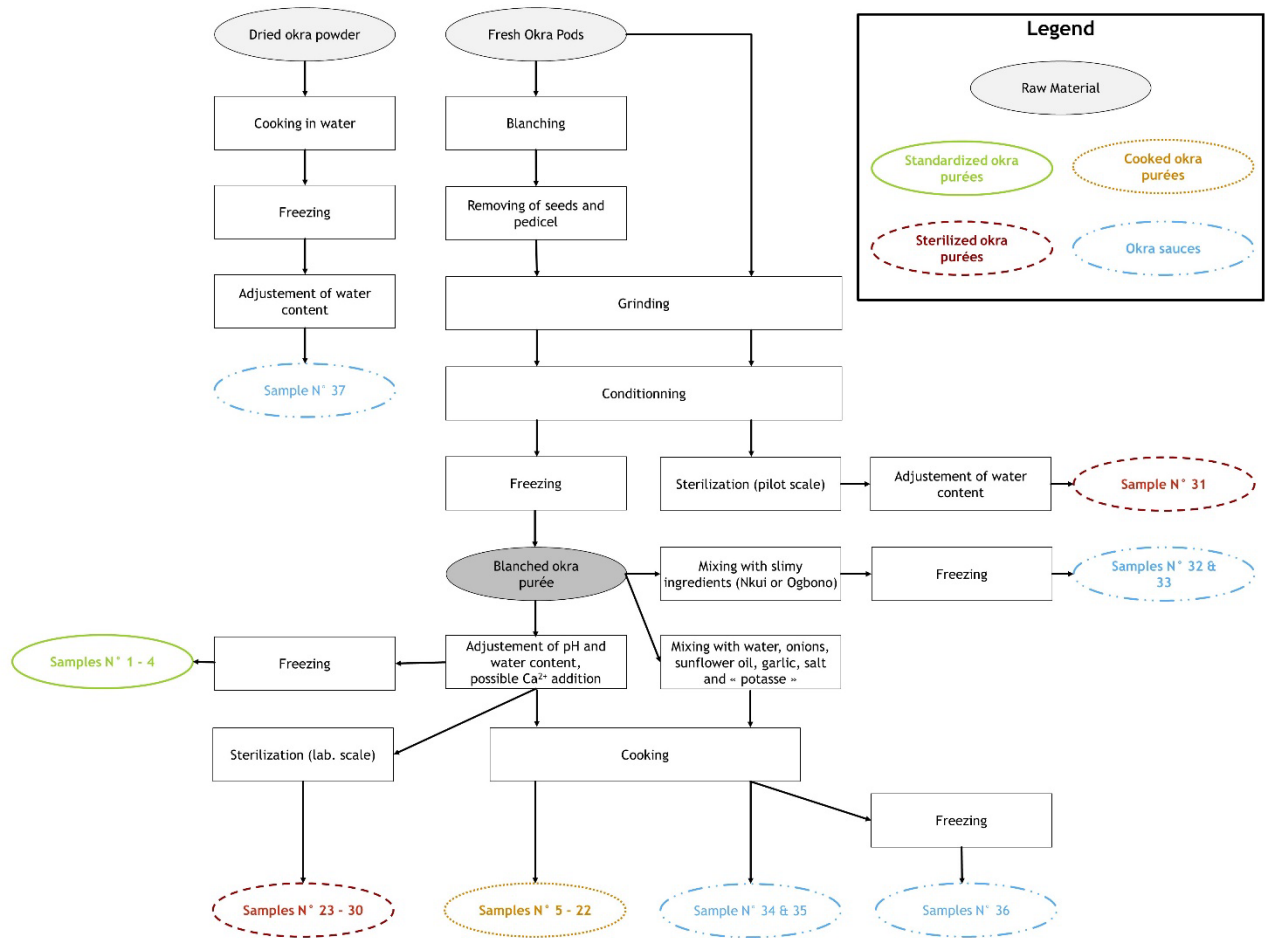
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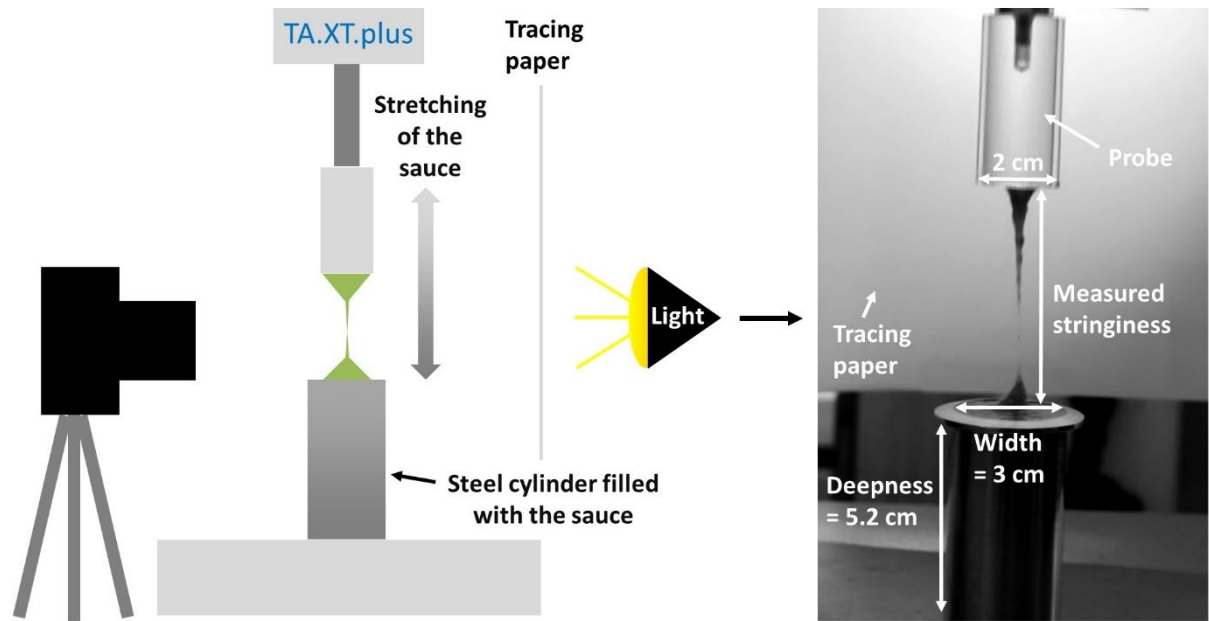
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703 Figure 2: Drawing of the experimental set-up for measuring the stringiness



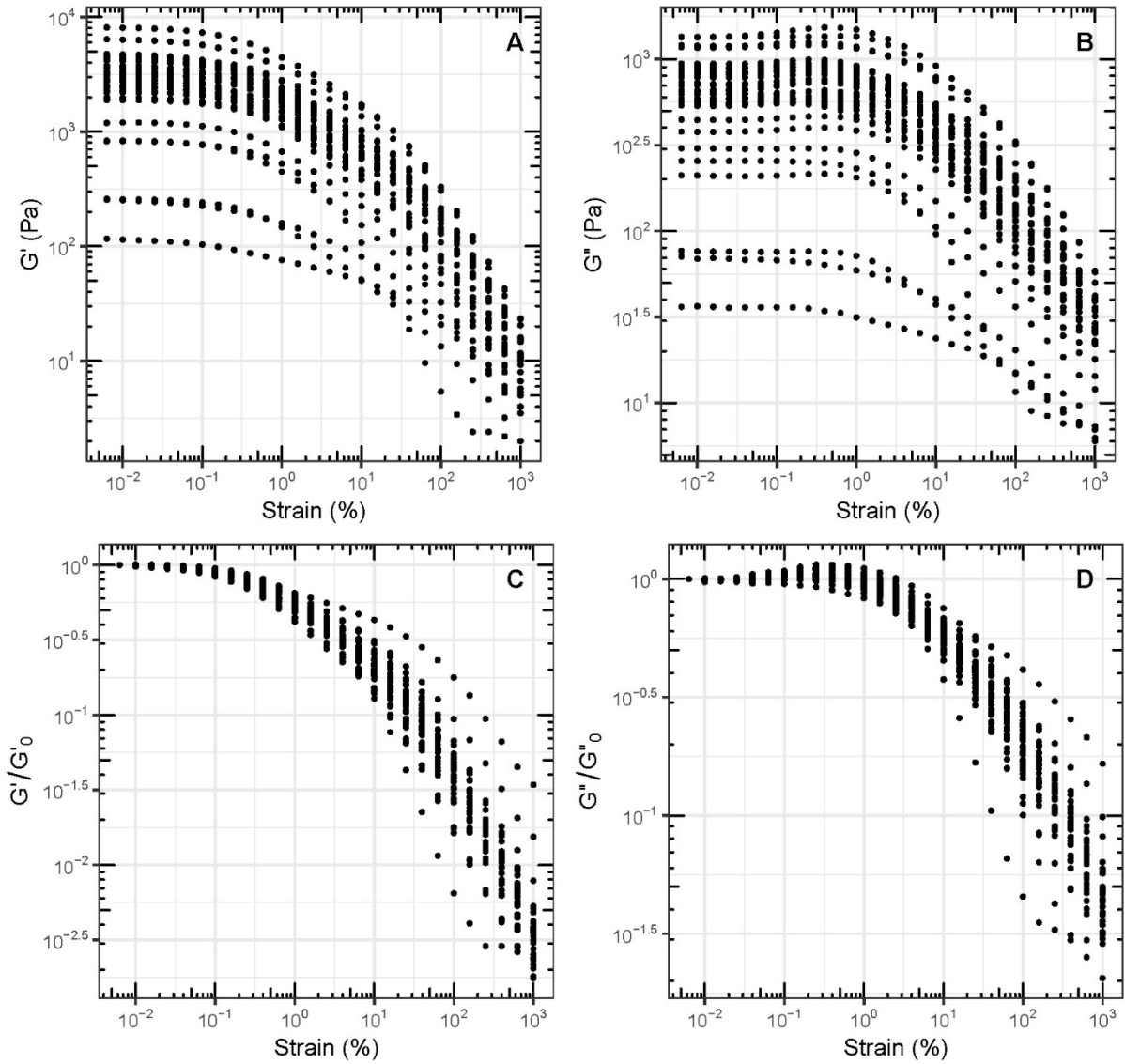
- 704 1) Recording of the stretching with a camera → 2) Extraction of the image corresponding to maximum breaking length of the filament with VLC → 3) Measurement of the stringiness with Image J

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710 (see (Hyun et al. 2002)).

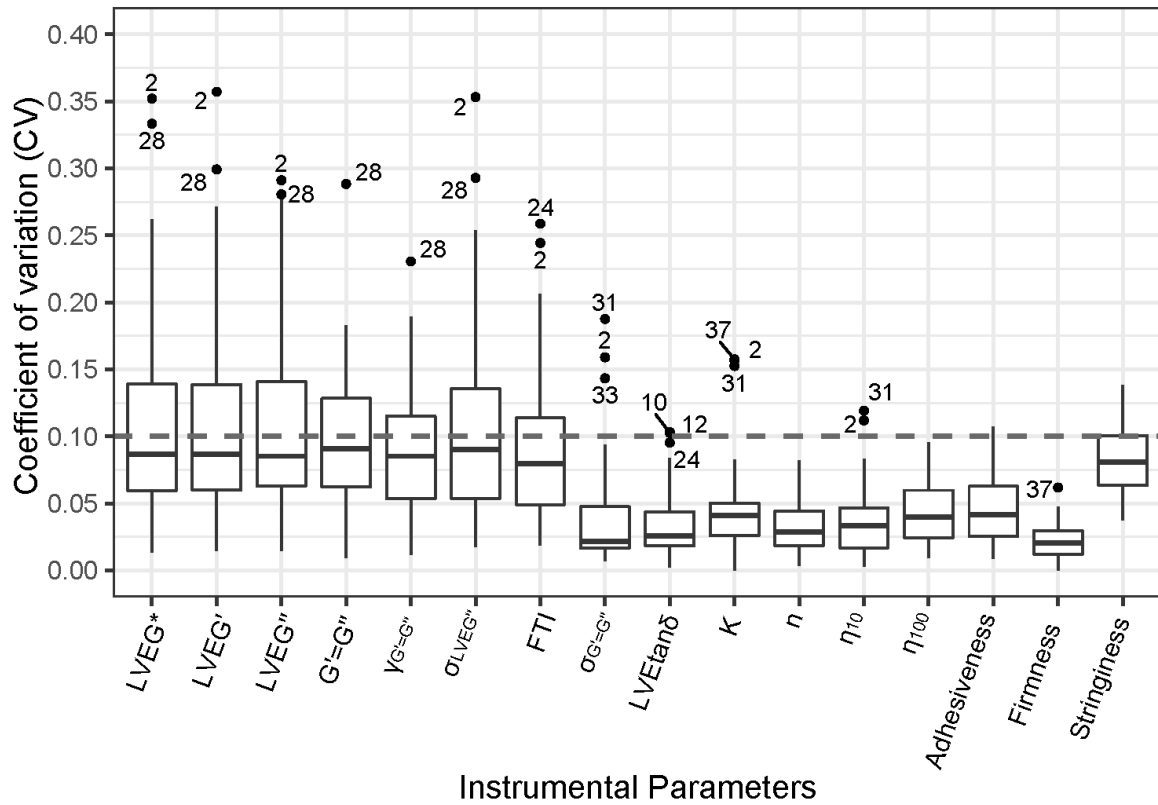


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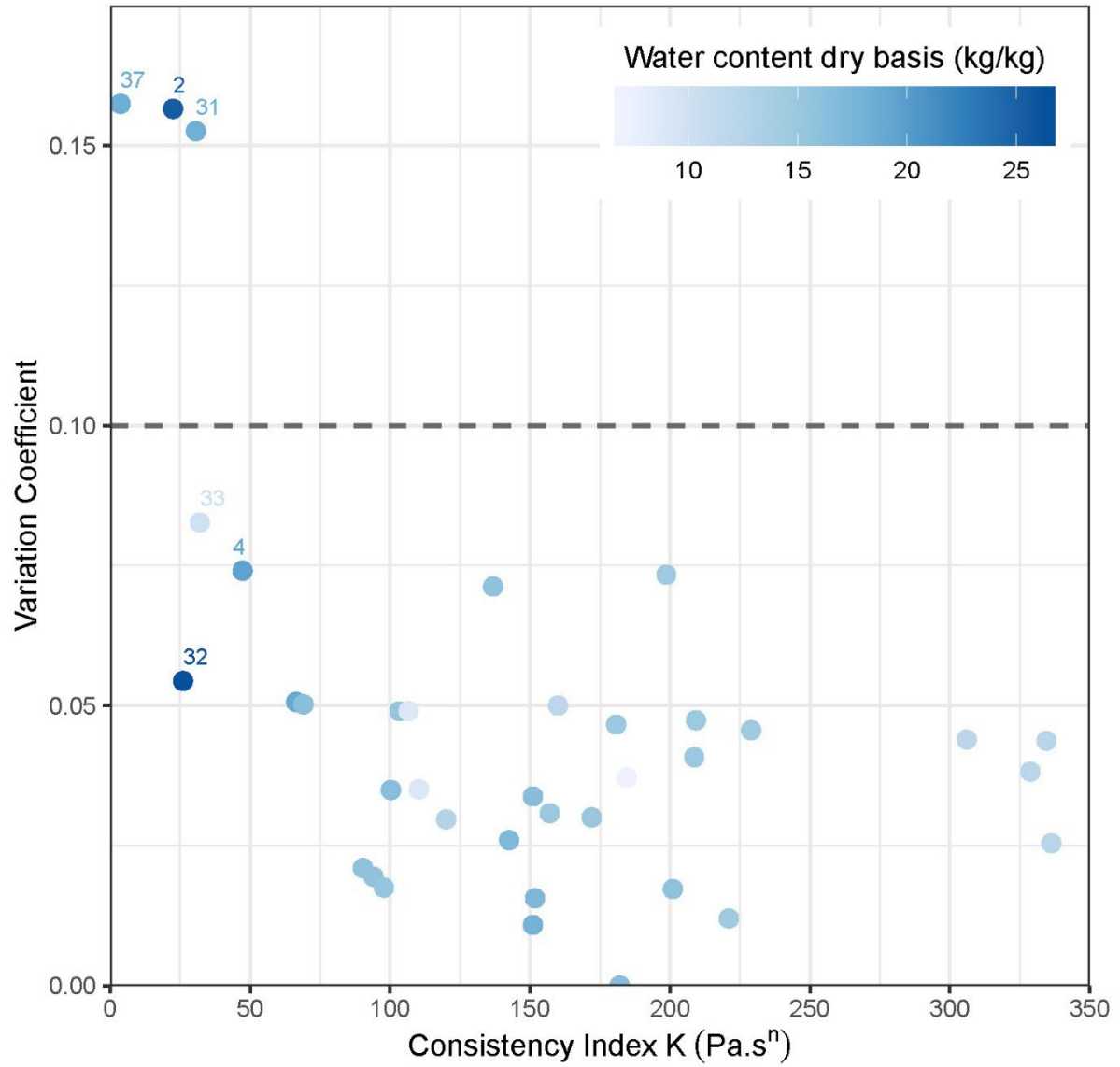
714 Figure 4: Distribution of Variation Coefficients (CV) measured on the 37 samples for the 16
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 716 been measured. The 10% dash line corresponds to the threshold above which the measurement was
 717 not considered repeatable.



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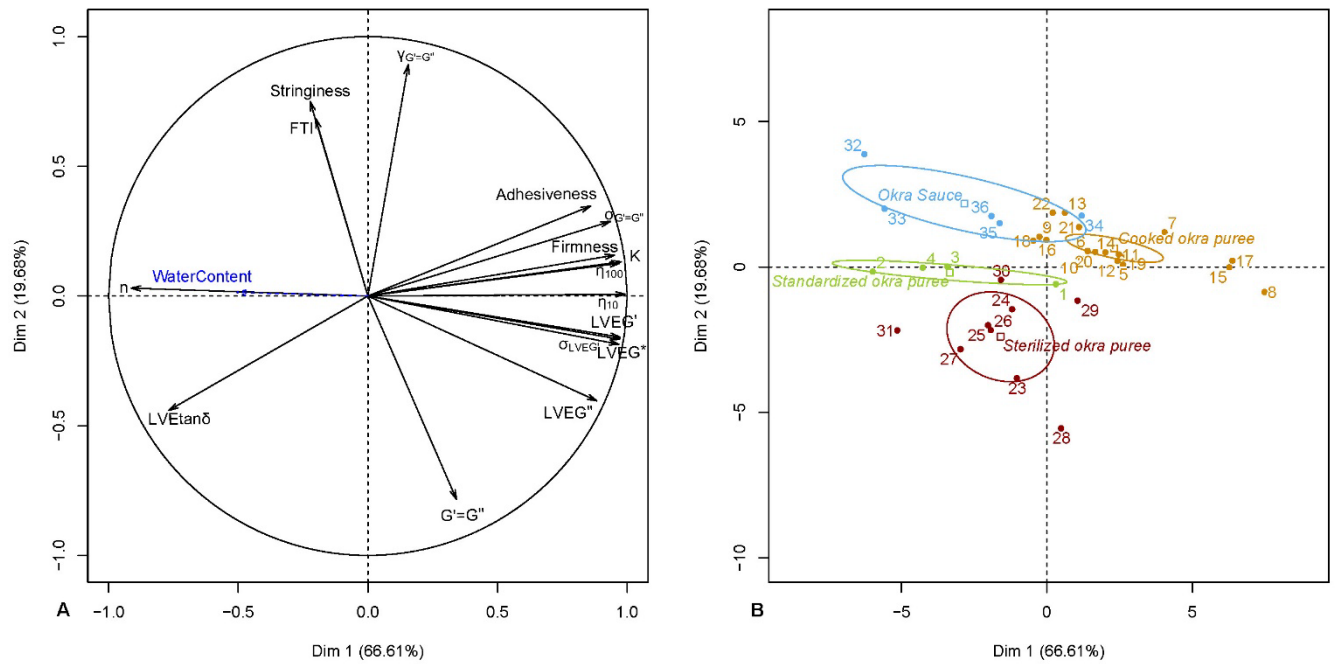
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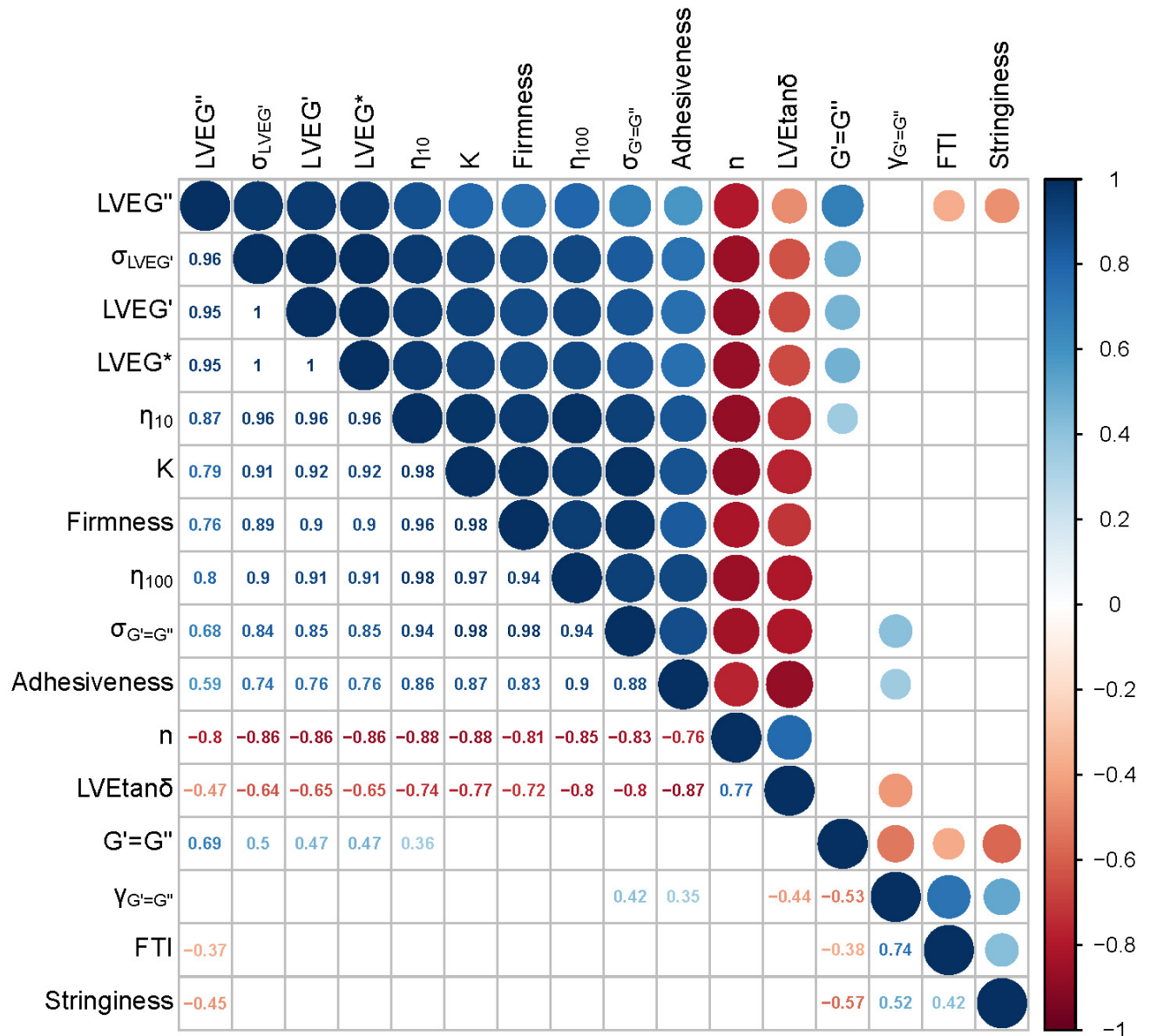
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727 Figure 6: Principal Component Analysis (PCA) biplot of the 16 textural and rheological parameters
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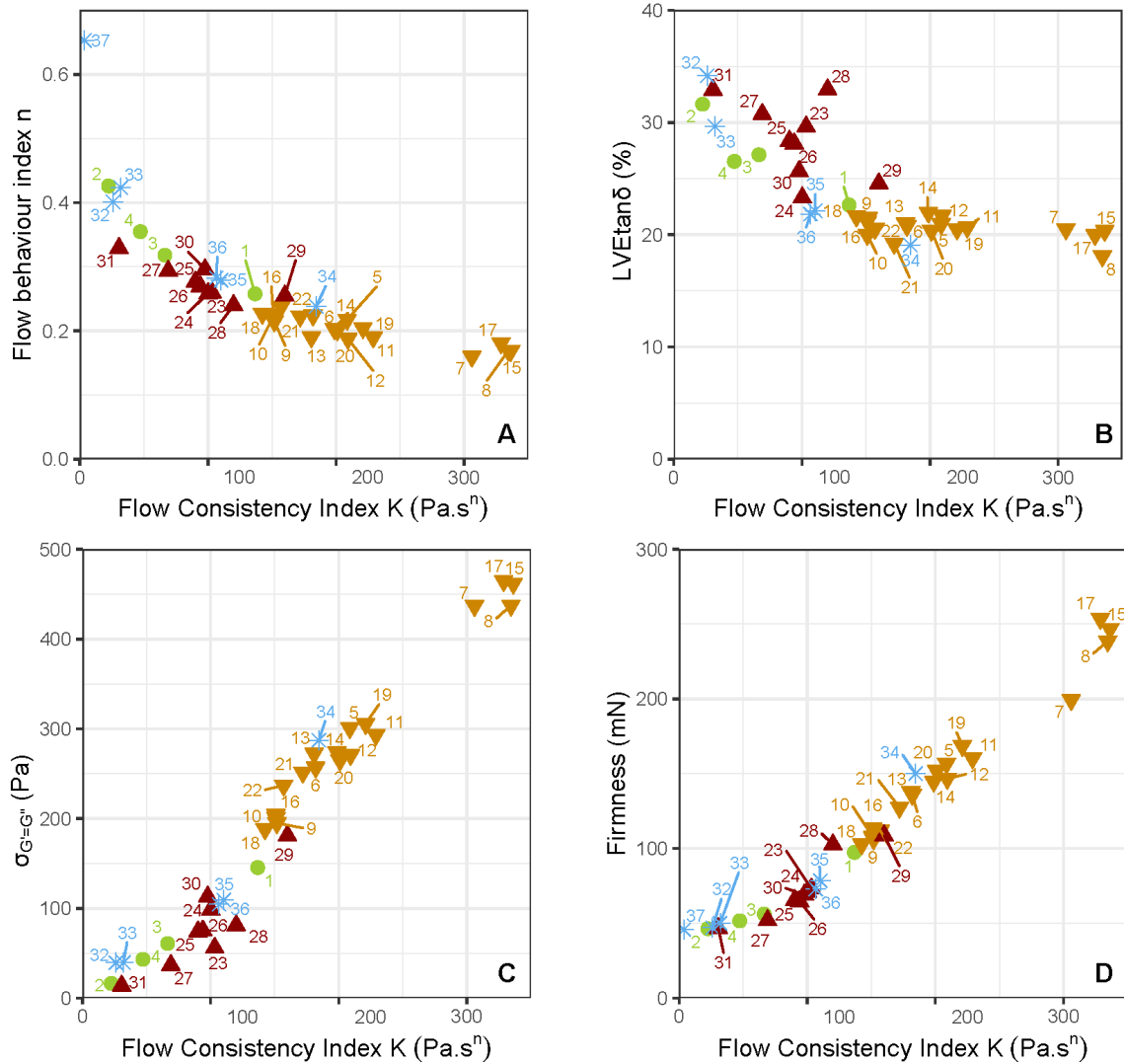
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 736 graphical representation of these coefficients: their color depends on the sign of the correlation
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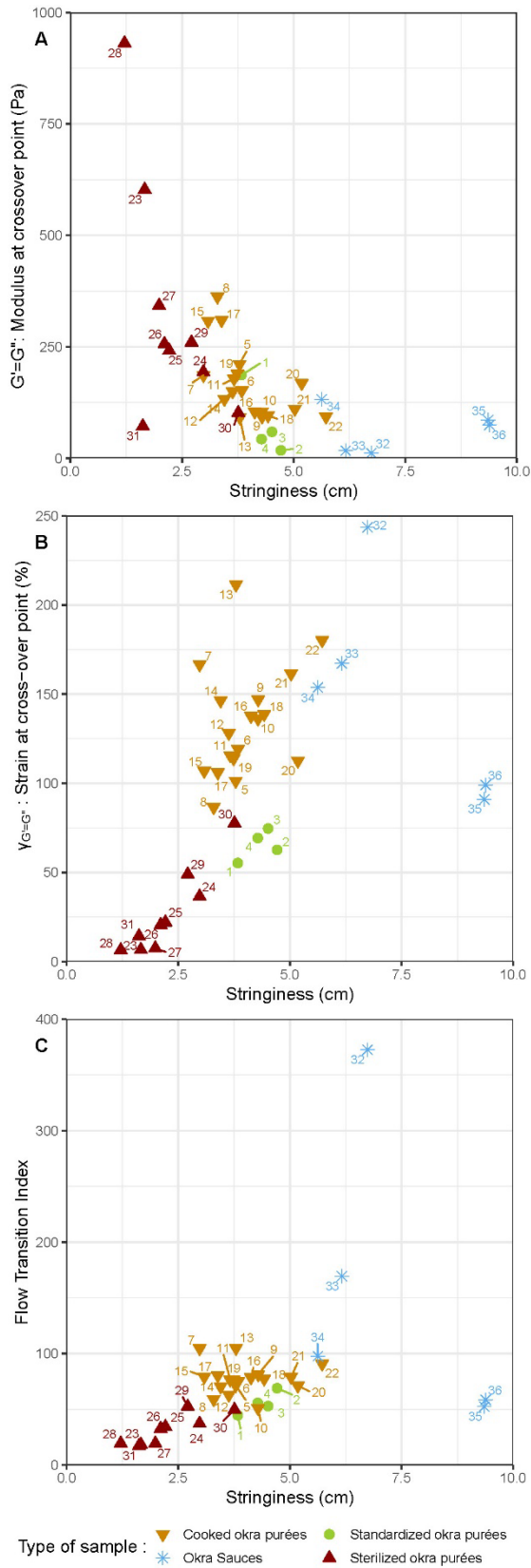


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Type of sample : ▼ Cooked okra puree ✱ Okra Sauce ● Standardized okra puree ▲ Sterilized okra puree

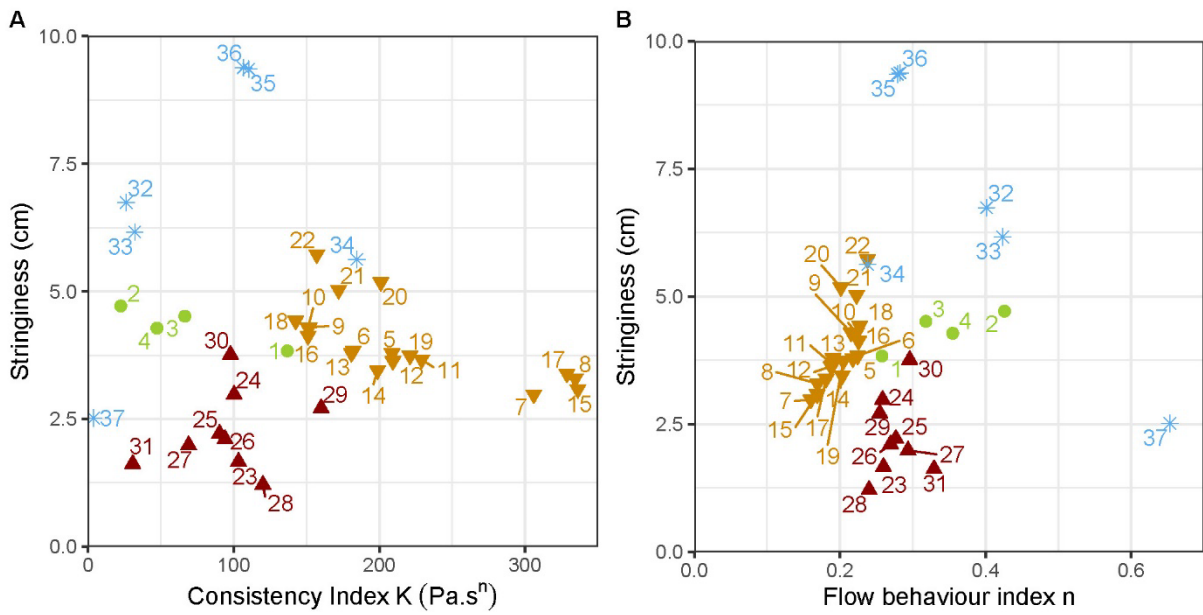
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749 Figure 9: Graphical illustrations of the correlation between stringiness and the main rheological and
750 textural properties of the second dimension of the PCA: $\gamma_{G'=G''}$ (A), $G'=G''$ (B), FTI (C).



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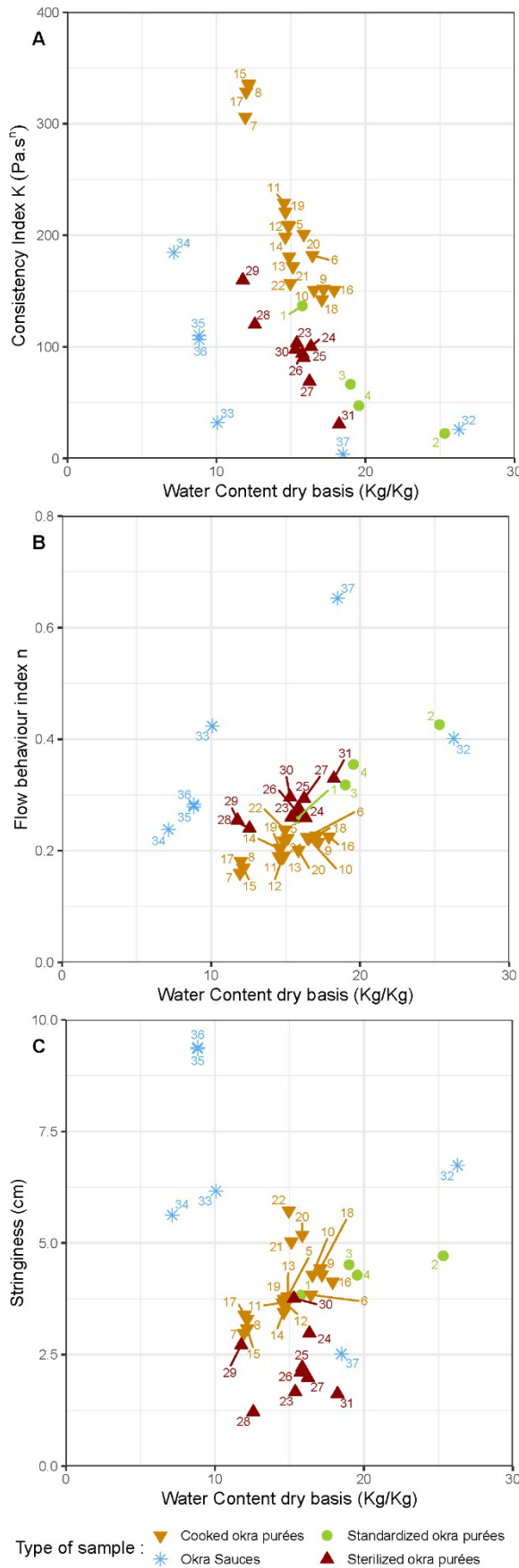


Type of sample : ▼ Cooked okra purées * Okra Sauces ● Standardized okra purées ▲ Sterilized okra purées

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756 Figure 11 : Water-dependence of flow consistency index K (A), flow behaviour index n (B) and
 757 stringiness (C) for the 37 suspensions



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