# Rheological study of cowpea puree 'adowe' and the influence of saliva on the puree viscosity

Teko, E., Ako, K., Yousefi, A., Munialo, C. D. & Osseyi, E Author post-print (accepted) deposited by Coventry University's Repository

#### Original citation & hyperlink:

Teko, E, Ako, K, Yousefi, A, Munialo, CD & Osseyi, E 2022, 'Rheological study of cowpea puree 'adowe' and the influence of saliva on the puree viscosity', International Journal of Food Science and Technology, vol. 57, no. 5, pp. 3098-3105. https://doi.org/10.1111/ijfs.15640

DOI 10.1111/ijfs.15640 ISSN 0950-5423 ESSN 1365-2621

**Publisher: Wiley** 

This is the peer reviewed version of the following article: [Teko, E, Ako, K, Yousefi, A, Munialo, CD & Osseyi, E 2022, 'Rheological study of cowpea puree 'adowè' and the influence of saliva on the puree viscosity', International Journal of Food Science and Technology, vol. 57, no. 5, pp. 3098-3105.], which has been published in final form at [https://doi.org/10.1111/ijfs.15640]. This article may be used for non-commercial purposes in accordance with Wiley Terms and Conditions for Use of Self-Archived Versions. This article may not be enhanced, enriched or otherwise transformed into a derivative work, without express permission from Wiley or by statutory rights under applicable legislation. Copyright notices must not be removed, obscured or modified. The article must be linked to Wiley's version of record on Wiley Online Library and any embedding, framing or otherwise making available the article or pages thereof by third parties from platforms, services and websites other than Wiley Online Library must be prohibited.

This document is the author's post-print version, incorporating any revisions agreed during the peer-review process. Some differences between the published version and this version may remain and you are advised to consult the published version if you wish to cite from it.

1	Rheological study of cowpea puree "adowè" and the influence of					
2	saliva on the puree viscosity					
3						
4	Authors and affiliations:					
5	Ekoué TEKO <sup>a</sup> , Komla AKO <sup>* b</sup> , Alireza YOUSEFI <sup>c</sup> , Claire D. MUNIALO <sup>d</sup> , Elolo OSSEYI					
6	a					
7	a) Laboratoire des Sciences Biomédicales, Alimentaires et Santé Environnementale					
8	(LaSBASE), ESTBA/Université de Lomé, BP : 1515, Lomé, Togo					
9	b) Univ. Grenoble Alpes, CNRS, Grenoble INP, LRP, 38000 Grenoble, France					
10	c) Department of Chemical Engineering, Faculty of Engineering, University of Bonab, 55517-					
11	61167, Bonab, Iran					
12	d) School of Life Sciences, Coventry University, Priory Street, Coventry, CV1 5FB UK					
13	*Corresponding author: komla.ako@univ-grenoble-alpes.fr; akokomla@hotmail.com					
14	Acknowledgements					
15	We thank Vincent Verdoot, Frédéric Hugenel and Eric Faivre for their technical supports.					
16	This work was financially supported by the educational ministry of TOGO. The Laboratoire					
17	Rhéologie et Procédés (LRP) is part of the LabEx Tec 21 (Investissements d'Avenir - grant					
18	agreement ANR-11-LABX-0030) and of the PolyNat Carnot Institut Investissements					
19	d'Avenir - grant agreement ANR-11-CARN-030-01).					
20						

### 22 Highlights

23

- <sup>24</sup> \* Cowpea seeds swell at all temperatures but cook at temperatures above 60 °C.
- \* The viscosity of cowpea puree decreases with shear rate and also decreases with time atconstant shear rate.
- 27 \* Cowpea puree exhibits creep recovery property. However, the concentration, stress, and
  28 shearing time control the recoverability.
- \* The cowpea puree could be assimilated to a non-Newtonian fluid with yield stress andrecoverable capacity.
- \* Saliva decreases the puree viscosity, but the relative impact is weak at very low or strongconcentrations.

#### 34 Abstract

Adowè is a traditional puree of cooked decorticated cowpea which can be used as part of a 35 36 healthy diet. However, the traditional preparation of adowe is laborious, time, water and fuel 37 consuming and this has resulted in a decline in its consumption. In this study, we investigated 38 the characteristics of adowe where powder-based products were used to formulate the puree 39 as a means of reducing the cost of the dish and promoting its consumption essentially by infants and or people with mastication difficulties. In the absence of additional salt, the 40 41 cooking of cowpea seeds was characterized by two activation energy domains from the swelling kinetics below and above 60 °C  $\pm$  5 °C of  $\approx$  15.30 kJ/mol and  $\approx$  28.35 kJ/mol 42 43 respectively. Decorticated seeds were completely cooked after  $\approx 60$  min at 90 °C and the 44 puree of 31 %  $\pm$  2 % (w/w) exhibited an apparent viscosity of  $\approx$  6 kPa.s at  $\approx$  0.1 /s and 23 °C 45 as determined by the back extrusion method. The purees exhibited a shear-thinning flow, time 46 decreasing viscosity at constant shear rate, and a partially recoverable capacity. At a shear rate 47 of 50 /s and for a shearing time of 80 s, the viscosity increased sharply by a factor 200 as the 48 concentration was increased from 12 - 20 % (w/w) by a factor 1.67. In the presence of saliva, 49 the viscosity was shown to remarkably decline with a greater impact for concentrations  $\approx 15$ 50 % (w/w).

51 Keywords: Cowpeas paste; Swelling; Cooking activation energy; Thixotropy; Textures;
52 Dysphagia

#### 54 **1. Introduction**

55 Cowpea (Vigna unguiculata L.) is an indigenous African legume crop. Its seeds (named 56 locally ayi in Togo) are widely consumed either alone or in combination with bread or staple 57 foods such as maize flour (djongoli), rice (ayimolu), root and tubers, cassava flour (gari), yam 58 and plantain in West and Central Africa (Edijala, 1980; Madodé, Houssou, Linnemann, 59 Hounhouigan, Nout & Van Boekel, 2011; Oniang'O, Mutuku & Malaba, 2003; Sodjinou, 2006). West and Central Africa dominates the global cowpea production with Nigeria 60 61 producing about 40 % of the global production (Adebooye & Singh, 2007; Gomez, 2004). 62 Cowpea seeds are cooked in a variety of ways to make the West African local dishes with their respective local names; boiled seeds (vevi in Togo, Benin), stew (abobo in Benin), puree 63 64 of decorticated beans (adowe and moin-moin in Togo, Benin and Nigeria), cowpea doughnut (gawù, ata, akara and koose in Togo, Benin, Nigeria and Ghana), and cowpea crêpe (kpedji-65 66 gawù in Togo) among others. Usually in Togolese traditional cuisines, black-eyed white 67 beans (Niébé) are preferred to cook adowe. Cowpea beans cooked alone (veyi) or with rice 68 (ayimolu) are the most popular dishes for cowpea consumers in Togo. Adowe is prepared by 69 steaming the decorticated cowpea seeds and crushing/mixing the cooked seeds into a puree 70 (Madodé, Houssou, Linnemann, Hounhouigan, Nout & Van Boekel, 2011). Adowè 71 consumption in Togo has remarkably dropped over the last couple of years. A survey that was 72 carried out in the framework of this study showed that the young generation of less than 30 73 years old are less familiar with adowe than the generation of their parents. The traditional 74 process of cooking adowe for domestic preparation and consumption is laborious, time and 75 water consuming (Madodé, Houssou, Linnemann, Hounhouigan, Nout & Van Boekel, 2011; 76 Oniang'O, Mutuku & Malaba, 2003). This could be one of the reasons that has resulted in a 77 decline in the contribution of adowe to the family diet, although the nutritional value of the 78 dish is still being appreciated. Purees are typical ways to introduce food to infants, to feed

toddlers and young children as well as for the elderly and geriatrics with mastication or swallowing difficulties, who as a consequence of lack of sufficient protein intake, are at an increased risk of losing lean body mass. Additionally, cowpea in grain form could be unsuitable in diets for people with impaired dental function, weakened oral cavity muscles, loss of natural teeth and declined movement coordination.

Scientific reports suggest that 50 g/day of dried beans can provide the recommended dietary reference intake of protein (Willett, Rockstrom, Loken, Springmann, Lang & Vermeulen, 2019). Given that cowpea seeds contain about 20 - 26 % (w/w) protein, (Edijala, 1980; Khan, Gatehouse & Boulter, 1980), it can be suggested that the consumption of approximately 220 g/day of the cowpea seeds as part of the traditional cuisines could be used as a strategy to ensure that the recommended dietary reference intake of protein is met.

90 Individuals with mastication or swallowing difficulties have an increased risk of protein 91 energy malnutrition hence there is a need to ensure that the foods that they consume have 92 sufficient quantities of protein. The preparation of cowpea to meet the textures of level 3 to 4 93 according to the International Dysphagia Diet Standardisation Initiative (IDDSI) classification 94 of food texture levels, i.e., moderately thick (liquidized) to extremely thick (pureed) 95 respectively, can help to promote a healthy diet among such individuals. Cowpea seed flour 96 can be used as a food ingredient to adjust the protein content and the texture of the food or to 97 prepare adowe e.g. for use in the preparation of moin-moin in order to alleviate the energy 98 cost that are involved in the domestic preparation of the puree from cooked cowpea seeds 99 (McWatters, 1990). However, cowpea powder-based products must meet the characteristics of 100 the traditional product in order to guarantee consumer acceptance of the products. Hence, 101 there is need to characterise the traditional product and use these characteristics in the 102 formulation of adowe from powder-based products.

103 In this study, we investigate the rheological properties of adowe following the traditional way 104 of cooking and determine the activation energy of cooking cowpea seeds. Several methods are 105 proposed by the IDDSI committee to evaluate the consistency of products. In this work we 106 studied the creep behavior, thixotropy, and shear thinning or thickening (Cichero et al., 2017; 107 Talens, Castells, Verdù, Barat & Grau, 2021) as function of shear rate, stress, time and the 108 concentration in the solid matter of adowe. The puree was diluted either by water or saliva to 109 study the influence of saliva on the flow behavior and to deduce the flow characteristic of the 110 puree in oral conditions (Laguna, Manickam, Arancibia & Tàrrega, 2020) although the 111 method implemented in this study is not a simulation of oral shear condition (SOSC).

#### 112 **2. Materials and methods**

#### 113 2.1The cowpea seeds

114 Cowpea seeds were purchased from a local market in Grenoble, France. Seeds with a clean 115 surface were selected. The seeds were decorticated by preheating the seeds in boiling water in 116 the presence of 1% (w/w) KOH for 5 min. The operation was continued manually by gently 117 rubbing the soaked seeds in between fingers to remove their coats. This procedure was carried 118 out at ambient temperature.

#### 119 2.2 The Saliva

Saliva was collected from a healthy adult individual donor according to the method described by (Yousefi & Ako, 2020). In summary, the donor was asked to rinse their mouth three times to remove any debris from their mouth cavity. Subsequently, a sterile piece of nylon sheet  $(\sim 5 \times 5 \text{ cm}^2)$  was given to the donor for chewing and this stimulated the secretion of saliva. The saliva was then obtained through spitting in a falcon tube. The fresh saliva was then kept at room temperature before being used in any test. The saliva was added to the puree of 126 concentrations 12 %, 15 %, 18 % and 20 % (w/w) to test the flow properties of the mixture at 127 37 °C. The shear rate for this test was 50 /s which was assimilated to the oral shear condition 128 of a young person. The four puree concentrations were then further diluted to have an initial 129 to final concentration ratio of 1:13 using saliva and water (as reference). The samples were 130 sheared during 80 s and the viscosity  $\eta_n$  for the two series of concentrations (initial and final) 131 were measured (indices n = p for puree without saliva (reference), n = ps for the puree with 132 saliva as respectively  $\eta_p$  and  $\eta_{ps}$ ).

- 133 2.3 Cowpea seeds cooking and the puree preparation
- 134 2.3.1 Swelling test during the cooking of the seeds

A number (4 seeds) of the cowpea seeds with their coats were placed in water and heated to different temperatures from 23 - 90 °C. The seeds were removed after a certain time and their weight was measured using a Sartorius balance (Germany). The swelling value was computed as:

139 
$$Q_t = \frac{w_t - w_0}{w_0}$$
 1

140 to define the relative amount of water uptake by the seeds at time t, where  $w_0$  was the initial 141 weight and  $w_t$  the weight of the seeds at time t. The experiment was carried out in duplicates.

142 2.3.2 Cowpea seeds puree preparation

The puree was prepared following the traditional processing method of cooking cowpea puree "adowè" (which in Togo is usually made by crushing the uncoated cooked seeds with a spatula) with slight modifications. The differences are mainly in the equipment used in this work. After decortication, the seeds were placed in boiling water in a seeds (175g) to water (526.9 g) proportion of 1:3 (w/w). The cooking time  $16 \pm 2$  min was determined according to the work of Téko et al. 2021 (Teko, Osseyi, Munialo & Ako, 2021). After cooking, the foam on the top of the seeds was removed and the remaining seeds in the cooked liquid were mixed with an ultra-turrax at 24000 rpm for 10 min to produce the stock cowpea puree and this will be referred to as cowpea seed puree (CSP). The solid matter concentration as determined by drying method for both the CSP and traditional product (adowè) was 31±2 % w/w.

#### 153 2.4 Compression and rheological tests

The viscosity and compression tests were performed using the HAAKE MARS-Modular Advanced Rheometer System (Thermo Scientific instrument, Germany), with a parallel geometry of 20 mm of diameter (TiLL11030P20) for the compression test and with a concentric cylinder geometry for the viscosity test. The measurement steps were controlled with the HAAKE RheoWin Job manager software 4.85.0002 (Thermo Fisher Scientific, Germany).

#### 160 2.4.1 Compression test

Four decorticated seeds were distributed in 4 x 20 ml containers and filled with 2 g of deionized water and heated to  $95 \pm 2 \,^{\circ}C$  in a water bath for different times. The compression tests were performed on cooked decorticated seeds following the procedure described by Téko et al. 2021 (Teko, Osseyi, Munialo & Ako, 2021). The original height of the cowpea seed is denoted as  $h_0$  and the height position of the geometry during the compression ( $h_t$ ) was recorded followed by calculating the deformation ( $\varepsilon_t$ ) at time *t* as:

167 
$$\varepsilon_t = (h_0 - h_t)/h_0$$

The compression tests were repeated four times using four seeds per heating time (10, 20, 30,
60, and 70 min) to give an average strain plot.

#### 171 2.4.2 Viscosity and creep-recovery tests

172 The creep-recovery and viscosity measurements were performed in concentric cylinder 173 geometry. It consists of an inner rotor cylinder (bob, type z38) with a radius  $R_1$  of 19 mm and 174 outer stator cylinder (cup, type CCB43/SS) with a radius R<sub>2</sub> of 21.5 mm, defining a radial gap 175  $(R_2 - R_1)$  of 2.5 mm. The height of the bob was 55 mm, and the vertical gap between the bob and cup was set at 2 mm. The maximum torque and force were  $2 \times 10^4$  µNm and 50 N 176 177 respectively. The torque M or the angular velocity  $\Omega$  was measured and the viscosity  $\eta$  was 178 derived as M and  $\Omega$  and are proportional to shear stress  $\sigma$  and shear rate  $\dot{\gamma}$  respectively by a 179 factor K<sub>G</sub> which is the geometric constant.

For extremely thick purees, the rheometer was used as a back extrusion method and the force of extrusion at constant linear velocity was shown to correlate with the viscosity quantity of the puree as:

184 where  $\Delta L$  is the displacement length of the bob in the puree, *v* is the velocity of the bob and 185 the  $\tilde{\eta}$  is proportional to viscosity. The linear velocity of the bob in the puree,  $v = -\Delta L/\Delta t$ , was 186 obtained during the penetration phase and was kept constant to 0.2 mm/s. The shear rate 187 gives:

188 
$$\dot{\gamma} = \frac{v}{R_2 - R_1} \approx 0.1 \text{ /s}$$
 4

this value was used for comparison of both the angular and linear shear viscosity.

In order to determine the values of compliance in the creep and recovery phases, 50 g of the purees were loaded to the rheometer. The puree samples were separately subjected to three constant stresses of 10, 50 and 100 Pa. Each stress was instantly applied and kept for a period of 300 s. The recovery phase was immediately started, so as the applied stress was instantlyremoved and strain recovery was measured for an additional period of 300s.

#### 195 2.5 Microscopy

Microscopy images were taken using the OLYMPUS IX73 (Japan) microscope with an oilimmersion ×20 objective to image adowe and CSP. Subsequently, both samples were diluted approximately five times to image the starch granules. The size of the starch granules of both samples were measured manually using image-J software.

#### 200 **3. Results and Discussion**

#### 201 3.1 Physical characteristics of cowpea seeds during cooking

#### 202 *3.1.1 The cooking activation energy*

The cooking process of cowpea seeds was characterized by swelling kinetics  $Q_t$  as amount of water uptake with time (Eq. (1)) (Coffigniez, Briffaz, Mestres, Akissoé, Bohuon & El Maâtaoui, 2019; Teko, Osseyi, Munialo & Ako, 2021). The slope ( $q_w$ ) of  $Q_t$  in Fig.1a was investigated to obtain the activation energies  $E_a$  of the cooking process using the Arrhenius equation (Eq. (5)).

$$208 \qquad q_w = k_0 \cdot e^{-E_a/RT}$$

5

where

210 
$$Ln(q_w) = Ln(k_0) - \frac{E_a}{R} \cdot \left(\frac{1}{T}\right)$$
 6

is a linear function of the inverse of temperature defining the factor  $E_a/R$  as the slope of Eq. (6) function; R = 8.314 J/K/mol is the perfect gas constant and  $k_0$  is the speed of swelling where swelling phenomena freely occurs at temperature *T*. The activation energy  $E_a$  of swelling changes when physico-chemical reactions like starch gelatinization, or protein denaturation begin as a result of the cooking process (Coffigniez, Briffaz, Mestres, Akissoé, Bohuon & El Maâtaoui, 2019; Tolkach & Kulozik, 2007). Fig.1a shows the kinetics of water absorption by the seeds for a range of temperatures from 23 - 90 °C. The results show that the absorption increases linearly with time following a slope  $q_w$  as illustrated by the dash lines in Fig.1a. The slope increases when the temperature is increased.



Figure 1: a) Time evolution of the cowpea seeds swelling at different temperatures. The dash lines represent linear regression of the data before the kinetics reach a plateau. b) Inverse of temperature dependence of the swelling rate for the temperature T < 50 °C and  $\geq 60$  °C

The  $q_w$  obtained from Fig.1a were reported in Fig.1b as a function of the inverse of temperature (1/T) and shown in semi logarithmic scale following Eq. (6). The results show clearly two thermal activation energy  $E_a$  domains of the swelling kinetics, below 60 °C and above 50 °C of 15.30 kJ/mol and 28.35 kJ/mol respectively. The increase of  $E_a$  could be due to the additional physico-chemical reactions which occur at temperature between 55 °C - 65 °C (Tolkach & Kulozik, 2007). Above 60 °C, cooking the seeds could have only kinetics effects but at temperatures below 50 °C the seeds should be considered as under cooked.

The cooking time of the decorticated seeds was determined at  $95 \pm 2$  °C using the method of Teko et al., (2021) (Teko, Osseyi, Munialo & Ako, 2021). The seeds were compressed at 0.1 N force and the time-dependence of their deformation  $\varepsilon_t = (h_0 - h_t)/h_0$  was measured (Fig.2a), then the compression data were analyzed using the model of Eq. (7).

236 
$$\varepsilon_t = (\varepsilon_0 - \varepsilon) \cdot e^{-N_t} + \omega \cdot t^{\beta} + \varepsilon$$
 7

237 with

$$238 \qquad N_t = \left(t/t_c\right)^{\alpha} \qquad 8$$

In the Fig.2a the intersection between the dash line and the deformation axis gives  $\varepsilon$  and the slope of the dash line represents the coefficient  $\omega$  as  $(\varepsilon_f - \varepsilon)/t_f$ , where  $\varepsilon_f$  is where the deformation function reach a plateau at a time defined as final time  $(t_f)$  in the case of elastic seeds at constant applied force.



Figure 2: a) Time dependence of the deformation of the cowpea seeds (without coat) for the cooking time of 30 min at a constant compressive force of 0.1 N. The cooking temperature

was  $95 \pm 2$  °C and the seeds to water weight ratio was 1:3. The full lines are fits to Eq.(7) and the dotted lines are linear regression of the asymptotic evolution of the deformation kinetic to yield  $\varepsilon$  and  $\omega$  taking  $\beta \approx 1$  for all the fits. b) Cooking time dependence of  $\omega$ . The dash line is connection of the dots.

The coefficient  $\omega$  characterizes the seeds softness and its dependence on the cooking time as shown in Fig.2b could demonstrate the cooking progression. The transition of the uncoated seeds at 95 ± 2 °C between uncooked and completely cooked state starts roughly 10 ± 3 min after the seeds were added to the boiling water and lasts  $\approx$  35 min. In the middle of the transitioning regime, some seeds were disintegrated. The quantity of seeds which were disintegrated increased with increasing cooking time. Therefore the cooking time was fixed to 16 ± 2 min which could correspond to the beginning of the cooking processes.

#### 257 **3.2** The cowpea puree characteristics

258 The appearance of both adowe and CSP is shown in Fig.3a, b. The surface of adowe looks 259 more irregular with visually thick textures (the product kept cavities/surface deformations 260 over several hours). The CSP was also of a thick texture but with a fine surface. The 261 magnification  $\times 20$  of the images (insert in Fig.3a, b) show that the laboratory puree (CSP) 262 was smoother, and brighter, than the traditional puree (adowè). When the 31 % (w/w) purees 263 were diluted to 20 % (w/w), the products lost their capacity to hold cavities but left smooth 264 lines on their surface, which demonstrates a high thickness level (Fig.3c). The dilution to 20 265 % (w/w) allowed larger starch clusters to dissolve leading to a fine distribution of the starch 266 granules.



267

Figure 3:Images of the traditional puree (adowè) (a, Trad.) and the laboratory puree (CSP) made in laboratory (b, Lab.), the inserts are the images after magnification ×20, c) cowpea puree at 20 % used for rheological studies and d) a representative microscopic image of both adowè and CSP.

Diluting the purees to concentrations lower than 12 % (w/w) led to sedimentation of the starch granules during the experimentation. The granulometric (Fig.3d) of adowe and CSP showed a strong similarity with granules of the population of size  $\approx 100 \pm 50 \ \mu$ m. However, the adowe still contained a few population of starch clusters of sizes within the range of  $600 \pm 200 \ \mu$ m which was not observed in CSP.

#### 277 3.3 Rheological properties of the puree: influence of saliva

#### 278 3.3.1 Creep-recovery and flow behavior of cowpea puree as influenced by saliva

The creep-recovery tests have shown a viscous liquid behavior for the samples of 12 % (w/w), because at the lowest applied stress (10 Pa) no recovery of this concentration was observed, whilst the sample 20 % (w/w) exhibited an elastic like behavior (Fang et al., 2020) for the applied stress range [10 Pa -100 Pa] (figure SI.1 in supplementary information). The recoverable capacity of the intermediate concentrations diminishes when the applied stress during the creep phase increases as a result of an existence of yield stress that increases with the solid matter concentration (figure SI.2 in supplementary information). Typical flow curves of CSP samples show the shear-thinning flow behavior of all samples (figure SI.3 in supplementary information). As the shear rate increased, the apparent viscosity decreased. The power-law model (Eq. (9)) adequately fitted the shear viscosity-shear rate data ( $R^2 = 0.98$ -0.99; RMSE = 0.04 - 0.41) (Steffe, 1996):

in which, k (Pa.s<sup>n</sup>) and n are the power-law flow consistency coefficient and flow behavior 291 292 index, respectively. As the concentration of the cowpea seed puree increased from 12 % to 20 % (w/w), its flow consistency coefficient (k) increased drastically (from 3.27 to 203.45 Pa.s<sup>n</sup>), 293 294 while its flow behavior index (n) diminished (from 0.55 to 0.16), which means more 295 pseudoplastic behavior (Table 1 in SI). The same behavior has been attained for native and 296 modified starch purees (Yousefi & Razavi, 2015), starch-carbohydrate purees (Liu, Li, Fan, 297 Zhang & Zhong, 2019; Ma, Zhu & Wang, 2019; Pourfarzad, Yousefi & Ako, 2021; Yousefi 298 & Ako, 2020), cereal, and legume flour puree (Pang, Cao, Li, Chen & Liu, 2020).

Fig.4 shows the influence of saliva on the viscosity of the samples. The relative impact of the saliva,  $(\eta_p - \eta_{ps})/\eta_p$ , on the puree viscosity is shown in the insert of Fig.4. The purees viscosity dropped in presence of saliva, but the degree of the impact was dependent on the range of concentrations, i.e. 40 % for 12 % and 75 ± 3 % for concentrations range between 15 % and 20 % (w/w) (insert of Fig.4). These results led to the classification of three ranges of concentrations: i) below  $\approx$  15 % where the impact of saliva is low (< 50 %) as diluted or liquid, ii) between  $\approx$  15 % and  $\approx$  20 % where the impact of saliva is high (> 50 %) as 306 intermediate, and iii) above 20 % (w/w) where the impact of saliva is again low as extremely



308



309 Figure 4: The concentration dependence of the viscosity at the conditions (50 /s, 80 s) in the 310 absence  $(\eta_p)$  and in the presence of saliva  $(\eta_{ps})$ , the insert shows the rate of dropping down 311 the viscosity by the addition of saliva.

312 The National Dysphagia Diet (NDD) limits provide a comprehensive and clinical approach 313 for dysphagia management. Based on NDD limits, a liquid or liquid-like food with a viscosity 314 more than 0.35 Pa.s (honey-like) is suitable for the people with dysphagia (Garin, De Pourcq, 315 Martin-Venegas, Cardona, Gich & Mangues, 2014). The apparent viscosity  $n_{50}$  at 50 /s and at 316 room temperature (25 °C) is generally used as a standard rheological measurement for the 317 classification of the foods for dysphagia management (Cho & Yoo, 2015; Talens, Castells, 318 Verdù, Barat & Grau, 2021). According to this classification, it can be deduced that all the 319 cowpea seed puree samples with concentration higher than 12 %(w/w) examined in this work 320 could fall within the category of foods that are easy to swallow by the people with dysphagia.

The viscosity was not measurable in the range of stress [0, 100 Pa] for the concentration 20 % 322 323 (w/w). The range of stress where it was difficult to use the rheometer to measure the viscosity 324 of the puree widened with an increase in the concentration. Therefore, the back extrusion 325 method was used to perform the measurement of the viscosity of the 31 % (w/w) puree. For 326 the sake of comparison, two shear modes (angular and linear) were applied on the 15 % (w/w) 327 concentration at same shear rate of  $\approx 0.1$  /s to get the factor between the two viscosity  $\eta$  and  $\tilde{\eta}$ 328 parameters. In Fig.5 three regimes of (I), (II) and (III) were identified by the penetration of the 329 bob in the sample, i.e., from gap 50 mm (outside the sample) to 2 mm (inside the sample).



330

Figure 5: Back extrusion forces at constant velocity (0.2 mm/s) as function of axial position of
the bob for 31 % (w/w) puree.

In the regime (III), resistance results mainly from the air but in this regime the contact of the bob section with the puree induces partial contact friction from gap 40 mm to reach full contact friction from gap 20 mm. The penetration forces increases linearly with the gap from 336 gap 20 mm to 10 mm in the regime (II), but sharply from gap 10 mm to 2 mm as compaction 337 increases the puree resistance in this regime. Therefore, the bob did not reach the gap of 2 mm 338 before the test was automatically stopped given that the force limit (50 N) of the instrument 339 was reached. The lifting tests showed that the bob left the sample between a gap of 15 and 20 340 mm which correspond to regime (II) where the viscosity of the puree was computed as

$$341 \qquad \tilde{\eta} = -\frac{\Delta F}{\Delta L \cdot \nu} \tag{10}$$

where the slope in the regime (II) of the Fig.5 was -1.62 N/mm. The test for 15 % gave  $\tilde{\eta} \approx$ 1400× $\eta$ . The viscosity of the puree of 31 % (w/w) at  $\approx$  0.1 /s obtained by the back extrusion method was  $\tilde{\eta} \approx$  8 MPa.s, hence  $\eta \approx$  6 kPa.s.

#### 345 **4.** Conclusion

In the absence of additional salt, cowpea seeds swell without cooking following an activation 346 energy of  $\approx$  15.30 kJ/mol and start cooking above 60 ± 5 °C with an activation energy of  $\approx$ 347 28.35 kJ/mol. The completely cooked time shrunk from  $\approx$  80 min to  $\approx$  60 min at 95 ± 2 °C 348 349 when the seeds were decorticated. However, the decorticated seeds were prone to bursting 350 during the cooking process. The viscosity of the CSP at  $31 \pm 2$  % (w/w) concentration as 351 determined by back extrusion method was  $\approx 6$  kPa.s at  $\approx 0.1$  /s and 23 °C. The purees 352 exhibited a shear-thinning flow and time decreasing viscosity behavior at constant shear rate. 353 At constant shear rate 50 /s and for a shearing time of 80 s, the viscosity increased sharply by a factor 200 as the concentration was increased from 12 % to 20 % (w/w) by a factor 1.67. 354 355 The creep-recovery test demonstrated the recoverable capacity of the puree, but the capacity 356 to relax the stress decreased with the concentration of the solid matter and time or with the 357 increase of the applied stress. Hence, the puree flow behavior is assimilated to a non-358 Newtonian fluid with a yield stress and recoverable capacity which declined in the presence

of saliva. The impact of saliva was greater for concentrations around 15 % (w/w) for which the viscosity shrunk by 80 %. The results of this study could be useful for optimizing the cooking energy cost and the food texture quality in industrial processing of cowpea puree.

#### **362 5. Declaration of competing interest**

363 The authors declare no conflicts of interest.

#### 364 **6. References**

- 365 Adebooye, O. C., & Singh, V. (2007). Effect Of Cooking On The Profile Of Phenolics,
  366 Tannins, Phytate, Amino Acid, Fatty Acid And Mineral Nutrients Of Whole-Grain
- 367 And Decorticated Vegetable Cowpea (*Vigna Uuguiculata L. Walp*). Journal of food
  368 Quality, 30(6), 1101-1120.
- Cho, H. M., & Yoo, B. (2015). Rheological characteristics of cold thickened beverages
  containing xanthan gum–based food thickeners used for dysphagia diets. *Journal of the Academy of Nutrition and Dietetics, 115*(1), 106-111.
- 372 Cichero, J. A. Y., Lam, P., Steele, C. M., Hanson, B., Chen, J., Dantas, R. O., Duivestein, J.,
- 373 Kayashita, J., Lecko, C., Murray, J., Pillay, M., Riquelme, L., & Stanschus, S. (2017).
- 374 Development of International Terminology and Definitions for Texture-Modified
- Foods and Thickened Fluids Used in Dysphagia Management: The IDDSI Framework. *Dysphagia*, *32*, 293-314.
- 377 Coffigniez, F., Briffaz, A., Mestres, C., Akissoé, L., Bohuon, P., & El Maâtaoui, M. (2019).
- 378 Impact of soaking process on the microstructure of cowpea seeds in relation to solid
  379 losses and water absorption. *Food Research International*, *119*, 268-275.
- Edijala, J. K. (1980). Effects of processing on the thiamin, riboflavin and protein contents of
   cowpeas (*Vigna unguiculata (L) Walp*). I. Soaking, cooking and wet milling processes
   *Journal of Food Technology*, *15*, 435-443.

- 383 Fang, F., Luo, X., BeMiller, J. N., Schaffter, S., Hayes, A. M. R., Woodbury, T. J., Hamaker,
- B. R., & Campanella, O. H. (2020). Neutral hydrocolloids promote shear-induced
  elasticity and gel strength of gelatinized waxy potato starch. *Food Hydrocolloids, 107*.
- 386 Garin, N., De Pourcq, J. T., Martin-Venegas, R., Cardona, D., Gich, I., & Mangues, M. A.
- 387 (2014). Viscosity differences between thickened beverages suitable for elderly patients
  388 with dysphagia. *Dysphagia*, *29*, 483-488.
- 389 Gomez, C. (2004). Cowpea: Post-harvest operations. *Food and Agriculture Organization of*390 *the United Nations (FAO)*, 71.
- Khan, M. R. I., Gatehouse, J. A., & Boulter, D. (1980). The Seed Proteins of Cowpea (Vigna unguiculata L.Walp.). *Journal of Experimental Botany*, *31*(125), 1599-1611.
- Laguna, L., Manickam, I., Arancibia, C., & Tàrrega, A. (2020). Viscosity decay of
  hydrocolloids under oral conditions. *Food Research International*, *136*(109300).
- Liu, D., Li, Z., Fan, Z., Zhang, X., & Zhong, G. (2019). Effect of soybean soluble
  polysaccharide on the pasting, gels, and rheological properties of kudzu and lotus
  starches. *Food Hydrocolloids*, *89*, 443-452.
- Ma, S., Zhu, P., & Wang, M. (2019). Effects of konjac glucomannan on pasting and
   rheological properties of corn starch. *Food Hydrocolloids*, *89*, 234-240.
- 400 Madodé, Y. E., Houssou, P. A., Linnemann, A. R., Hounhouigan, D. J., Nout, M. J. R., & Van
- Boekel, M. A. J. S. (2011). Preparation, Consumption, and Nutritional Composition of
  West African Cowpea Dishes. *Ecology of Food and Nutrition*, *50*, 115-136.
- 403 McWatters, K. H. (1990). Functional characteristics of cowpea flours in foods. *Journal of the*404 *American Oil Chemists'Society*, 67(5), 272-275.
- 405 Oniang'O, R. K., Mutuku, J. M., & Malaba, S. J. (2003). Contemporary African food habits
  406 and their nutritional and health implications. *Asia Pacific Journal of Clinical*407 *Nutrition, 12*(3), 231-236.

- Pang, Z., Cao, J., Li, H., Chen, C., & Liu, X. (2020). Rheology and tribology properties of
  cereal and legume flour paste from different botanical origins. *Journal of Food Science*, 85(12), 4130-4140.
- 411 Pourfarzad, A., Yousefi, A., & Ako, K. (2021). Steady/dynamic rheological characterization
  412 and FTIR study on wheat starch-sage seed gum blends. *Food Hydrocolloids*, *111*.
- 413 Sodjinou, R. S. (2006). Evaluation of food composition tables commonly used in Benin:
- 414 Limitations and suggestions for improvement. *Journal of Food Composition and* 415 *Analysis*, *19*, 518-523.
- 416 Steffe, J. F. (1996). Rheological methods in food process engineering. *Freeman press, East*417 *Lancing, USA*.
- Talens, P., Castells, M. L., Verdù, S., Barat, J. M., & Grau, R. (2021). Flow, viscoelastic and
  masticatory properties of tailor made thickened pea cream for people with swallowing
  problems. *Journal of Food Engineering, 292*(110265).
- 421 Teko, E., Osseyi, E., Munialo, C. D., & Ako, K. (2021). The transitioning feature between
- 422 uncooked and cooked cowpea seeds studied by the mechanical compression test.
  423 *Journal of Food Engineering*, 292.
- Tolkach, A., & Kulozik, U. (2007). Reaction kinetic pathway of reversible and irreversible
  thermal denaturation of b-lactoglobulin. *Lait*, *87*, 301-315.
- 426 Willett, W., Rockstrom, J., Loken, B., Springmann, M., Lang, T., & Vermeulen, S. (2019).
- 427 Our food in the anthropocene: The EAT-Lancet commission on healthy diets from 428 sustainable food systems. *The Lancet*, *393*(10170), 447-492.
- 429 Yousefi, A. R., & Ako, K. (2020). Controlling the rheological properties of wheat starch gels
- 430 using Lepidium perfoliatum seed gum in steady and dynamic shear. *International*
- 431 *Journal of Biological Macromolecules, 143*, 928-936.

- 432 Yousefi, A. R., & Razavi, S. M. A. (2015). Steady shear flow behavior and thixotropy of
- 433 wheat starch gel: Impact of chemical modification, concentration and saliva addition.
- 434 Food Process Engineering, 39(1), 31-43.
- 435
- 436

# Rheological study of cowpea puree "adowè" and the influence of saliva on the puree viscosity

\*Corresponding author: komla.ako@univ-grenoble-alpes.fr; akokomla@hotmail.com

## **Supplementary Information (SI)**



*SI.1:* Creep recovery tests of the cowpea seed purees with different concentrations (w/w) at a constant stress indicated in the figure.



**SI.2:** The stress dependence of the viscosity for the concentration of 12 %, 15 % and 20 % (w/w) to show the influence of the concentration on the yield stress respectively illustrated by the arrow 1, 2 and 3 which correspond respectively to the couple (stress, shear rate): (1 Pa,  $3 \times 10^{-3} \text{ s}^{-1}$ ), (10 Pa,  $3 \times 10^{-3} \text{ s}^{-1}$ ) and (120 Pa,  $15 \times 10^{-3} \text{ s}^{-1}$ ).



SI.3: Typical flow curves of cowpea seed purees with different concentrations

Samplas	$\eta = k \dot{\gamma}^{n-1}$				$\mathbf{p}$ ( $\mathbf{p}_{\mathbf{q}}$ $\mathbf{q}$ )
Samples	k (Pa.s <sup>n</sup> )	n	R <sup>2</sup>	RMSE	$\eta_{50}(Fa.s)$
12%	3.27	0.55	0.98	0.04	0.483
15%	50.11	0.17	0.99	0.07	1.884
18%	60.83	0.19	0.99	0.09	2.522
20%	203.45	0.16	0.99	0.41	10.5

**Table 1**: The parameters of Power-law model for the cowpea seed purees with different concentrations (w/w) and apparent viscosity ( $\eta_{50}$ ) at 50 s<sup>-1</sup>.