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Highlights

* 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 at constant shear rate.

* Cowpea puree exhibits creep recovery property. However, the concentration, stress, and shearing time control the recoverability.

* The cowpea puree could be assimilated to a non-Newtonian fluid with yield stress and recoverable capacity.

* Saliva decreases the puree viscosity, but the relative impact is weak at very low or strong concentrations.

Abstract

Adowè is a traditional puree of cooked decorticated cowpea which can be used as part of a healthy diet. However, the traditional preparation of adowè is laborious, time, water and fuel consuming and this has resulted in a decline in its consumption. In this study, we investigated the characteristics of adowè where powder-based products were used to formulate the puree 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 cooking of cowpea seeds was characterized by two activation energy domains from the swelling kinetics below and above 60 °C ± 5 °C of ≈ 15.30 kJ/mol and ≈ 28.35 kJ/mol respectively. Decorticated seeds were completely cooked after ≈ 60 min at 90 °C and the puree of 31 % ± 2 % (w/w) exhibited an apparent viscosity of ≈ 6 kPa.s at ≈ 0.1 /s and 23 °C as determined by the back extrusion method. The purees exhibited a shear-thinning flow, time decreasing viscosity at constant shear rate, and a partially recoverable capacity. At a shear rate of 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 - 20 % (w/w) by a factor 1.67. In the presence of saliva, the viscosity was shown to remarkably decline with a greater impact for concentrations ≈ 15 % (w/w).

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

1. Introduction

Cowpea (*Vigna unguiculata L.*) is an indigenous African legume crop. Its seeds (named locally ayi in Togo) are widely consumed either alone or in combination with bread or staple foods such as maize flour (djongoli), rice (ayimolu), root and tubers, cassava flour (gari), yam and plantain in West and Central Africa (Edijala, 1980; Madodé, Houssou, Linnemann, Hounhouigan, Nout & Van Boekel, 2011; Oniang'O, Mutuku & Malaba, 2003; Sodjinou, 2006).West and Central Africa dominates the global cowpea production with Nigeria producing about 40 % of the global production (Adebooye & Singh, 2007; Gomez, 2004). Cowpea seeds are cooked in a variety of ways to make the West African local dishes with their respective local names; boiled seeds (veyi in Togo, Benin), stew (abobo in Benin), puree of decorticated beans (adowè 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-gawù in Togo) among others. Usually in Togolese traditional cuisines, black-eyed white beans (Niébé) are preferred to cook adowè. Cowpea beans cooked alone (veyi) or with rice (ayimolu) are the most popular dishes for cowpea consumers in Togo. Adowè is prepared by steaming the decorticated cowpea seeds and crushing/mixing the cooked seeds into a puree (Madodé, Houssou, Linnemann, Hounhouigan, Nout & Van Boekel, 2011). Adowè consumption in Togo has remarkably dropped over the last couple of years. A survey that was carried out in the framework of this study showed that the young generation of less than 30 years old are less familiar with adowè than the generation of their parents. The traditional process of cooking adowè for domestic preparation and consumption is laborious, time and water consuming (Madodé, Houssou, Linnemann, Hounhouigan, Nout & Van Boekel, 2011; Oniang'O, Mutuku & Malaba, 2003). This could be one of the reasons that has resulted in a decline in the contribution of adowè to the family diet, although the nutritional value of the 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.

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

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.

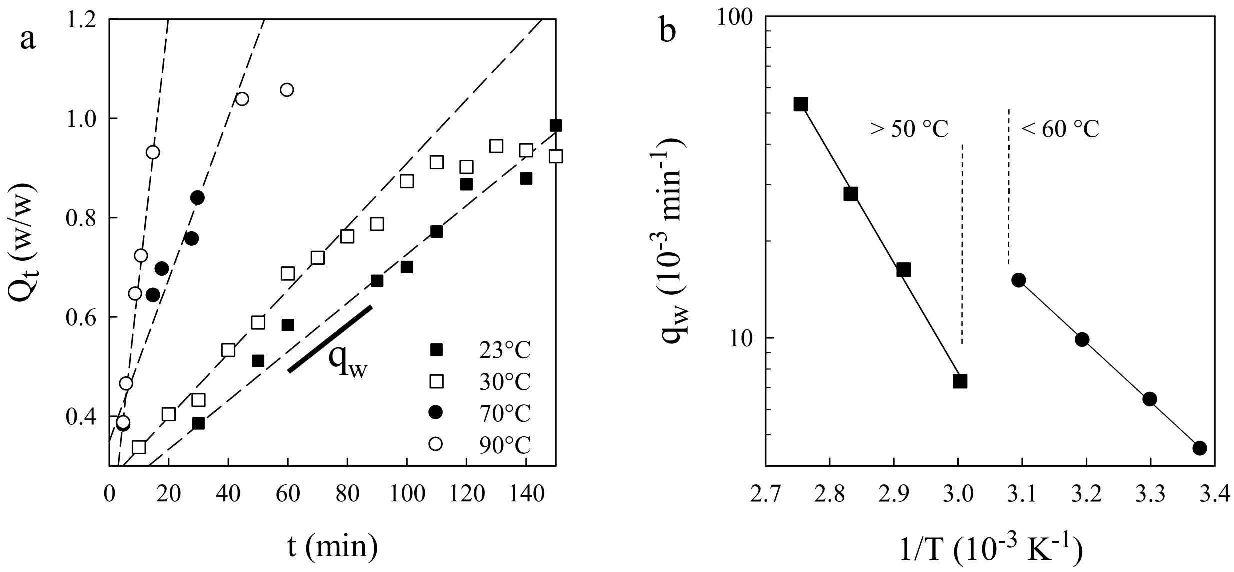

Figure 1: a) Time evolution of the cowpea seeds swelling at different temperatures. The dash lines represent linear regression of the data before the kinetics reach a plateau. b) Inverse of temperature dependence of the swelling rate for the temperature T < 50 °C and ≥ 60 °C

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.

3.1.2 Cooking time

The cooking time of the decorticated seeds was determined at 95 ± 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).

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

with

$$N_t = (t / t_c)^{\alpha} \quad (8)$$

In the Fig.2a the intersection between the dash line and the deformation axis gives ε and the slope of the dash line represents the coefficient ω as $(\varepsilon_f - \varepsilon)/t_f$, where ε_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.

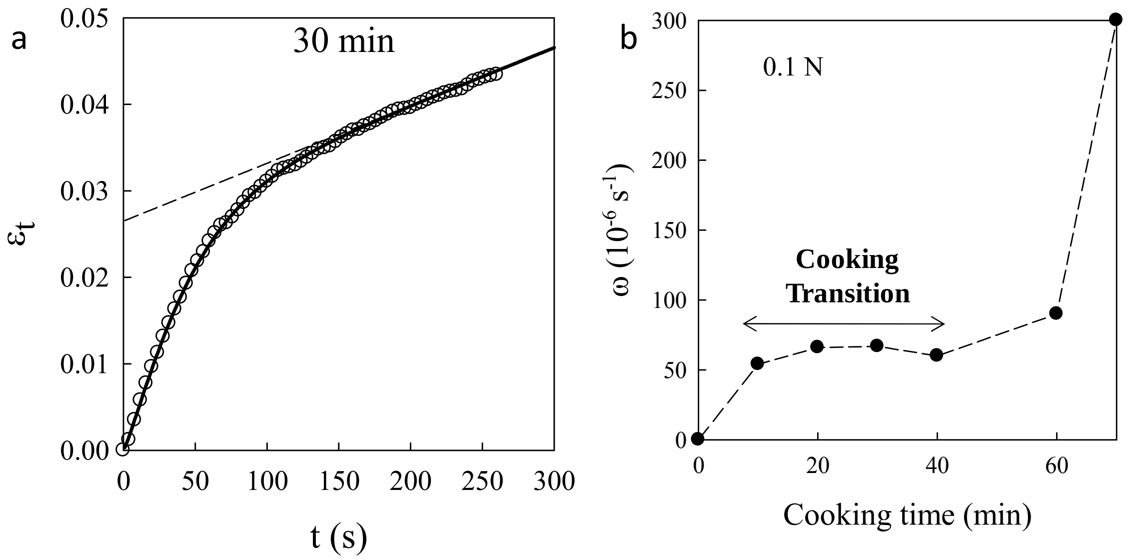

Figure 2: a) Time dependence of the deformation of the cowpea seeds (without coat) for the cooking time of 30 min at a constant compressive force of 0.1 N. The cooking temperature

was 95 ± 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 ε and ω taking β ≈ 1 for all the fits. b) Cooking time dependence of ω. The dash line is connection of the dots.

The coefficient ω 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 ≈ 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.

3.2 The cowpea puree characteristics

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

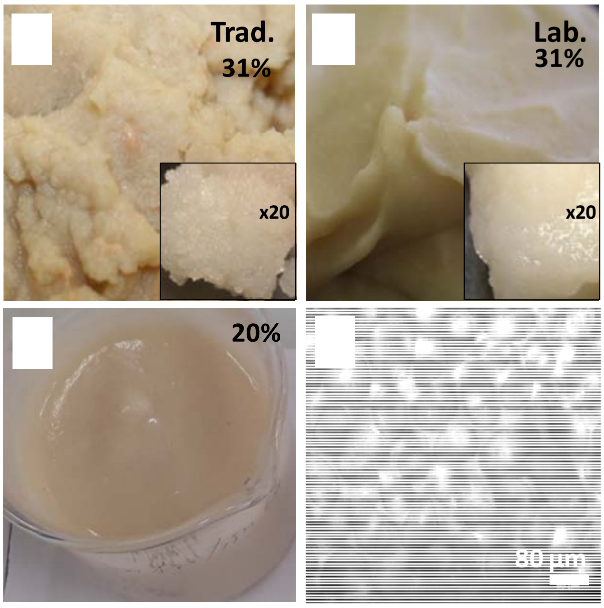

Figure 3:Images of the traditional puree (adowè) (a, Trad.) and the laboratory puree (CSP) made in laboratory (b, Lab.), the inserts are the images after magnification ×20, c) cowpea puree at 20 % used for rheological studies and d) a representative microscopic image of both adowè and CSP.

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 adowè and CSP showed a strong similarity with granules of the population of size ≈ 100 ± 50 μm. However, the adowè still contained a few population of starch clusters of sizes within the range of 600 ± 200 μm which was not observed in CSP.

3.3 Rheological properties of the puree: influence of saliva

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):

$$\eta = k\dot{\gamma}^{(n-1))} \qquad 9$$

in which, k (Pa.s^n) and n are the power-law flow consistency coefficient and flow behavior 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^n), while its flow behavior index (n) diminished (from 0.55 to 0.16), which means more pseudoplastic behavior (Table 1 in SI). The same behavior has been attained for native and modified starch purees (Yousefi & Razavi, 2015), starch-carbohydrate purees (Liu, Li, Fan, Zhang & Zhong, 2019; Ma, Zhu & Wang, 2019; Pourfarzad, Yousefi & Ako, 2021; Yousefi & 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 ≈ 15 % where the impact of saliva is low (< 50 %) as diluted or liquid, ii) between ≈ 15 % and ≈ 20 % where the impact of saliva is high (> 50 %) as intermediate, and iii) above 20 % (w/w) where the impact of saliva is again low as extremely thick or solid.

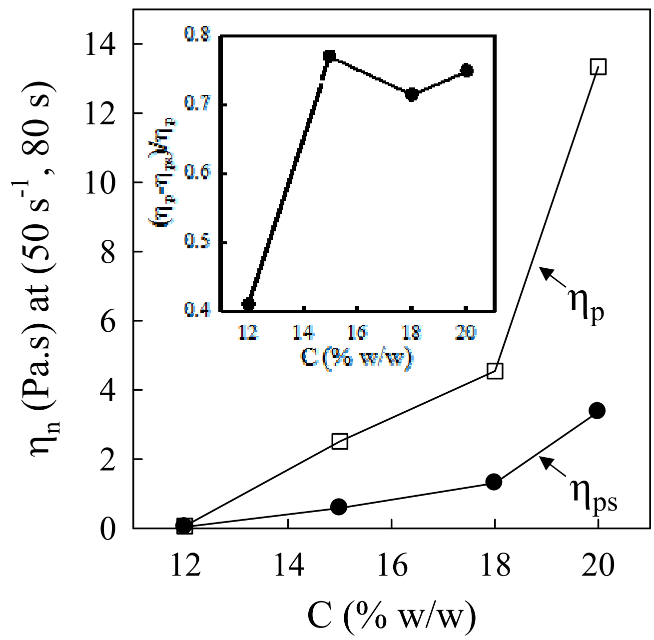

Figure 4: The concentration dependence of the viscosity at the conditions (50 /s, 80 s) in the absence (η_p) and in the presence of saliva (η_{ps}), the insert shows the rate of dropping down the viscosity by the addition of saliva.

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

3.3.2 Low shear viscosity of extremely thick puree

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

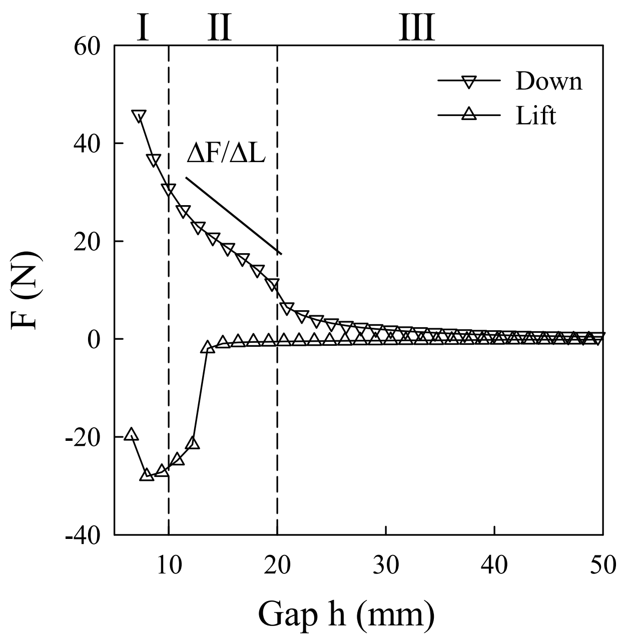

Figure 5: Back extrusion forces at constant velocity (0.2 mm/s) as function of axial position of the bob for 31 % (w/w) puree.

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 gap 20 mm to 10 mm in the regime (II), but sharply from gap 10 mm to 2 mm as compaction increases the puree resistance in this regime. Therefore, the bob did not reach the gap of 2 mm before the test was automatically stopped given that the force limit (50 N) of the instrument was reached. The lifting tests showed that the bob left the sample between a gap of 15 and 20 mm which correspond to regime (II) where the viscosity of the puree was computed as

$$\tilde{\eta} = -\frac{\Delta F}{\Delta L \cdot v} \qquad (10)$$

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

4. Conclusion

In the absence of additional salt, cowpea seeds swell without cooking following an activation energy of ≈ 15.30 kJ/mol and start cooking above 60 ± 5 °C with an activation energy of ≈ 28.35 kJ/mol. The completely cooked time shrunk from ≈ 80 min to ≈ 60 min at 95 ± 2 °C when the seeds were decorticated. However, the decorticated seeds were prone to bursting during the cooking process. The viscosity of the CSP at 31 ± 2 % (w/w) concentration as determined by back extrusion method was ≈ 6 kPa.s at ≈ 0.1 /s and 23 °C. The purees exhibited a shear-thinning flow and time decreasing viscosity behavior at constant shear rate. 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. The creep-recovery test demonstrated the recoverable capacity of the puree, but the capacity to relax the stress decreased with the concentration of the solid matter and time or with the increase of the applied stress. Hence, the puree flow behavior is assimilated to a non-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.

5. Declaration of competing interest

The authors declare no conflicts of interest.

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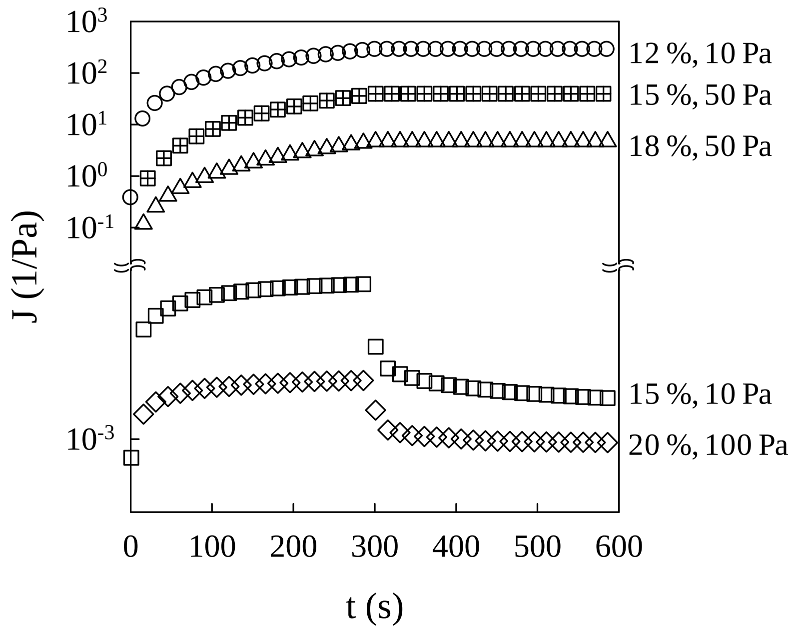
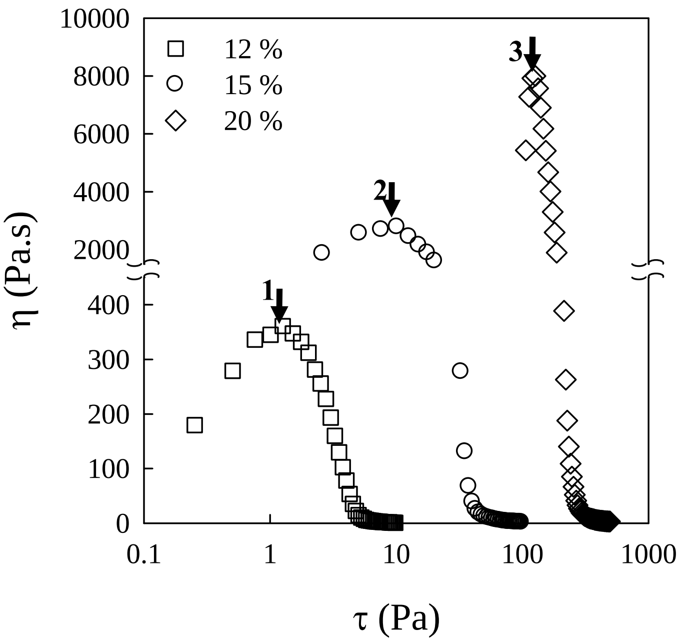
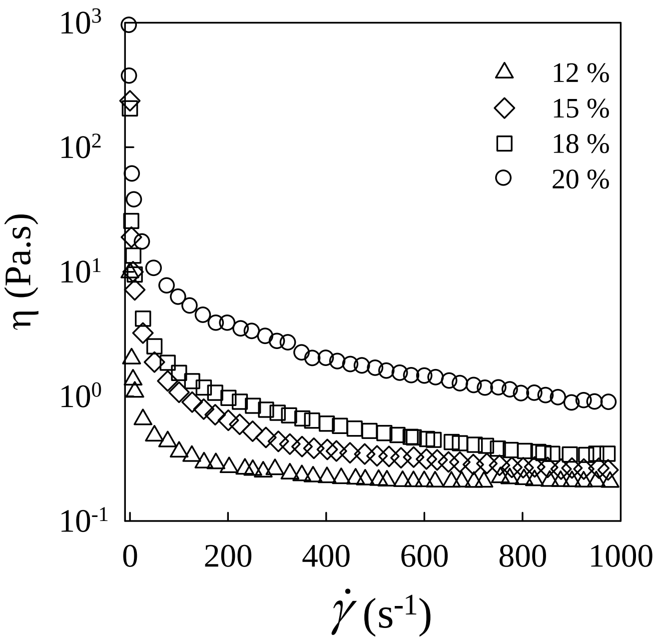
Supplementary Information (SI)



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, 3×10^{-3} s^{-1}), (10 Pa, 3×10^{-3} s^{-1}) and (120 Pa, 15×10^{-3} s^{-1}).*



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

Samples	$\eta = k\dot{\gamma}^{n-1}$				η_{50} *(Pa.s)*
	k (Pa.s^n)	**n**	**R^2**	**RMSE**	
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 (η_{50}) at 50 s^{-1}.*