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EFFECT OF SODIUM CHLORIDE SALT ON THE RHEOLOGICAL PROPERTIES OF SUNFLOWER OIL-IN-WATER EMULSION STABILIZED BY GELATINIZED BAMBARA GROUNDNUT FLOUR

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ABSTRACT

The influence of sodium chloride salt (NaCl) concentrations (0 – 300mM) on the rheological properties of sunflower oil-in-water emulsions (40 w/w%) stabilized by 7 w/w% gelatinized bambara groundnut flour (BGNF) was investigated. Rheological characterizations of the emulsions were carried out using a shear rate controlled rheometer. Emulsions with and without NaCl were thixotropic, pseudoplastic and viscoelastic fluids. The mean hysteresis loop area, consistency coefficient and recoverable strain were in the range 389.90 – 771.50 Pas^{-1}, 13.61 – 44.87 Pas^n and 10.82 – 46.15 % respectively. NaCl significantly affected ($p < 0.05$) rheological properties of BGNF-stabilized emulsion. Increased NaCl in the emulsion decreased extent of thixotropy, pseudoplasticity and viscoelasticity of BGNF-stabilized emulsions. The results indicated that the rheological properties of BGNF-stabilized emulsion can be controlled and manipulated using NaCl. The result provided the information necessary to understand the influence of NaCl on the rheological properties of BGNF-stabilized emulsions for product and process development.

Keywords: Bambara groundnut, emulsion, rheological properties, sodium chloride salt, oil-in-water.

Introduction

Emulsions are a class of dispersed systems that consist of two immiscible liquids, with one of the liquid dispersed as small droplets in the other called continuous phase (Adeyi et *al*., 2014). Rheological behaviour of an emulsion is among important emulsion properties. The knowledge of the rheological properties of food dispersions cannot be over emphasized for numerous reasons. Rheological data of food products are needed in shelf life testing, process engineering calculations, determination of ingredient functionality, quality control and in sensory evaluations (Steffe, 1996). Rheological data are also useful during food product development stage (Fischer and Windhab, 2011) and could address the industrial production of food (stirring, pumping, dosing, dispersing and spraying), home based cooking as well as consumption of food (oral perception, digestion and well-being) (Gao *et al.*, 2011). From a technological point of view, the rheology of food dispersions is fundamental mainly due to its relationships with emulsion stability (Gallegos *et al.*, 2004). Food emulsions are compositionally and structurally complex materials that can exhibit a wide range of different rheological behaviours, ranging from low viscosity fluids, to viscoelastic gels, to fairly hard solids (McClements, 2005). The rheological behaviour of particular food dispersion depends on the type and concentration of ingredients that it contains, as well as the processing and storage conditions (McClement and Jochen, 2005). Some other factors having profound effects on the properties of food emulsions are the aqueous phase compositions (Huck-Iriart *et al.*, 2011), salts (Martinez *et al.*, 2007), temperature and ageing (Gonçalves, and Maia Campos, 2009).

Improving the stability and rheological properties of emulsions through finding new alternatives is an increasingly growing area in food emulsion technology research. However, the unending demand for more natural products by the consumers and increasing legislations for safe and healthy food by governments has made synthetic emulsifiers in food systems increasingly unpopular. Finding natural emulsifier and stabilizers that have required functionalities in food systems has therefore remained a significant interest (Yang *et al.*, 2013) and challenge in food industries. The nutritional composition of bambara groundnut (BGN) indicates its potential as a natural food emulsifier/stabilizer and gelatinized bambara groundnut flour dispersion (BGNF) has been reported to stabilize sunflower oil-in-water emulsion (Adeyi *et al.*, 2014). BGN is a leguminous plant which belongs to the family fabaceae. BGN contained carbohydrate contents of 49 - 63.5%, protein content of about 15 – 25%, fat contents of about 4.5 - 7.4%, fiber content of 5.2 - 6.4, ash of 3.2 - 4.4% and 2% mineral (Murevanhema and Jideani, 2013). It has also been reported to have great health significance.

Sunflower oil-in-water emulsion stabilized by gelatinized BGNF is an emulsion system that may find applications in food industries because of its numerous desirable properties (Adeyi *et al.*, 2014). However, since most food emulsions contain sodium chloride as one of their ingredients during formulation, it is therefore necessary to investigate the influence of sodium chloride salt on the properties of sunflower oil-in-water emulsion stabilized by gelatinized BGNF to have a better understanding for product and process development in food industries. Therefore the objective of this study was to investigate the effect of sodium chloride salt on the rheological properties of sunflower-oil-in-water emulsion stabilized by gelatinized BGNF. This is important for the future adoption of BGNF as a natural stabilizer in food industry.

Experimental

Materials

Dried Bambara groundnut (BGN) seeds of brown variety were purchased from Triotrade Gauteng CC, South Africa. The seeds were washed, and dried at 50°C for 48 hrs by using cabinet drier (Model: 1069616). The dried seeds were milled into flour using a hammer mill and screened through 90 μm sieve to give bambara groundnut flour (BGNF). A commercial brand (Ritebrand) of 100% sunflower oil (SFO) purchased from a local supermarket was used without purification as the hydrophobic dispersed phase in this work. Milli-Q water was used in the preparation of all the emulsions. Food grade sodium chloride (NaCl) was purchased from a local store in Bellville, South Africa.

Emulsion preparation

Sodium chloride solution of various concentrations (25 – 300 mM) were prepared and used to prepare the continuous phase of the emulsions. Emulsions were prepared from a dispersed phase and a continuous phase according to Adeyi *et al.* (2014). The dispersed phase consisted of sunflower oil (SFO) and continuous phase was gelatinized bambara groundnut flour (BGNF) dispersion containing various NaCl concentrations (25 – 300 mM). Continuous phase was made by dispersing 7 g BGNF in 53 g of NaCl solutions. The resulting dispersions were gelatinized at a temperature of 84°C for 10 minutes with constant stirring. The resulting gelatinized BGNF dispersions (GBGNFD) were weighted in order to ascertain the amount of water loss during gelatinization. Water loss during gelatinization was compensated for by adding Milli-Q water to the GBGNFD, stirred and allowed to cool down to 20°C. SFO of 40 % (w/w) were added into the gelatinized BGNF. Emulsions (100 g) were made by homogenizing SFO and gelatinized BGNF at 20°C using an Ultra Turrax T-25 homogenizer (IKA, Germany) for 10 minutes at the speed of 11000 r/min.

Rheological measurement and modeling of emulsions

(A) Time dependent rheological measurement

Rheological measurements were conducted using a shear rate controlled rheometer (Rheolab MC 1, Physica Inc., Stuttgard Germany). All the experiments were performed at 20°C without previous shearing. Samples were carefully transferred into the rheometer cup and allowed to rest for about 10 minutes. Viscosity was measured as a function of increasing shear rate from 40 to 750 s^{-1} followed by a decreasing rate from 750 to 40 s^{-1}. In order to describe the time dependent flow behavior, experimental data (shear stress-shear rate) of forward and backward curves were fitted to Power law model. The hysteresis loop area was calculated as the area between the upstream data and downstream data using equation (1) (Koocheki and Razavi, 2009 and Tarrega *et al.*, 2004).

$$\text{Hysteresis loop area} = \int_{\gamma_1}^{\gamma_2} K\gamma^{n} - \int_{\gamma_1}^{\gamma_2} K'\gamma^{n'} \quad (1)$$

Where, K, K′ are the consistency coefficient and n, n' are the flow behavior indices for upward and downward measurements, respectively. Each experiment was performed in duplicate.

In the second part of this work, the time-dependent rheological properties were investigated by shearing oil-in-water emulsion stabilized with BGNF samples at 20 minutes at constant shear rate of 50 s^{-1}. Then the emulsion viscosity was measured as a function of shearing time. All measurements were done at a constant temperature of 20°C. The data were modeled in order to describe the time-dependent flow properties of the BGNF-stabilized emulsions using Weltman model (equation (2)).

$$\tau = A + B\, In(t) \quad (2)$$

Where, τ is the shear stress, t is the shearing time, and A and B are constants that characterize a material's time dependent behavior. Parameter *A* represents the initial shear stress and parameter *B*; the time coefficient of thixotropic breakdown is the product of rate in breakdown of thixotropic structure and time of agitation at constant rate of shear (Koocheki and Razavi, 2009).

(B) Oscillatory experiment

Oscillatory experiment was conducted using Discovery HR-1 rheometer (TA Instruments) equipped with temperature control. During the experiments, the temperature was maintained constant at 20ºC. Serrated parallel plates of 1 mm gap were used for all the experiments. Emulsions were carefully loaded into the rheometer and allowed to rest for 10 minutes before rheological test proceeded. Amplitude experiment were conducted at constant frequency of 6.28 rad/s and the storage and loss moduli were recorded as a function of stress (0.01 – 100 Pa). In order to determine the linear viscoelastic region, the storage modulus was plotted against shear stress. A shear stress of 0.1 Pa was afterwards selected for further frequency sweep experiment. Frequency sweep experiment was conducted at over a frequency range of 0.628 – 62.8 rad/s at a constant stress of 0.1 Pa which has been previously determined during amplitude test. The fingerprint of each emulsion sample in terms of storage and loss moduli was then plotted as a function of frequency. All experiments were duplicated.

(C) Creep and recovery experiment

Creep and recovery studies were conducted in a controlled stress Discovery HR-1 rheometer. Initial pre-shear of 300 s^{-1} was used on the emulsions for 240 s and equilibration time of 120 s was allowed before a creep and recovery experiment. During the creep-compliance experiment, fresh emulsion samples were suddenly subjected to a constant shear stress of 0.5 Pa which has been previously determined to be in the linear visco-elastic region (LVR). The deformation of the sample was recorded as a function of time during a period of 500 s. The stress was suddenly removed and the recoverable stress was further monitored for another 500 s. The linear visco-elastic region of the emulsions was determined by an amplitude sweep experiment in the range of 0.01 to 100 Pa at a frequency of 1 Hz and constant temperature of 20ºC prior to creep and recovery experiment. All experiments were duplicated.

Results and discussion

Effect of NaCl on the flow curves and hysteresis loop area

The rheological properties of the emulsions with and without NaCl can be assessed from their respective rheograms in Figure 1. The upper curves were developed first and therefore were at the top relative to the other and this showed that the emulsion samples were time dependent. The relative position of the curves with time showed that the structure of the emulsions was destroyed during the forward curve resulted in a decrease in shear stress during the backward curve. The structural destruction resulted into hysteresis loop areas created between the forward and the backward curves.

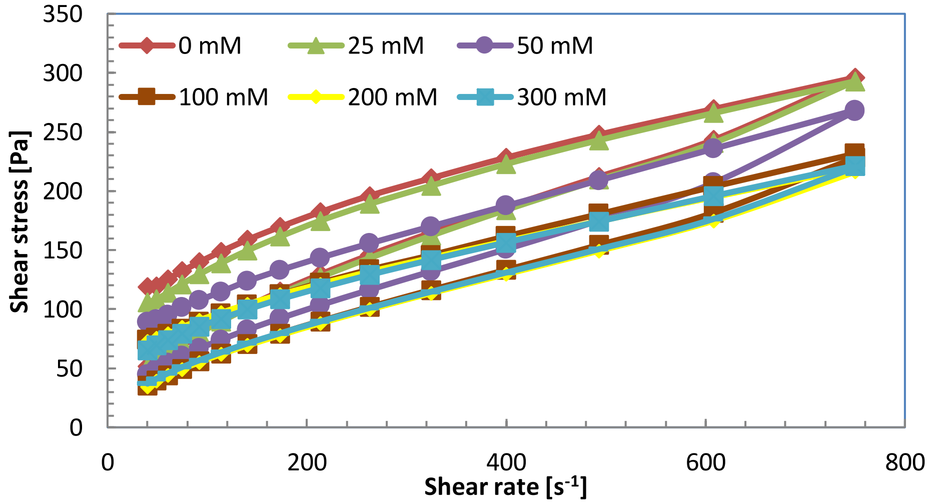

Figure 1. Effect of NaCl concentrations on the rheological behavior of optimized emulsion

All the emulsions exhibited hysteresis loop area irrespective of the concentration of the NaCl and the rheological behaviour of the emulsions with NaCl was similar to that of emulsion without NaCl. The existence of the hysteresis loop in the flow curves is an indication that the emulsions are thixotropic in nature. The viscosity of thixotropic fluids tends to decrease with shearing time, showing a marked structural destruction with time. Similar time-dependent properties were observed in oil-in-water emulsions containing vitamin C and derivatives at different concentrations (Goncalves and Maia Campos, 2009). Close examination of the ascending and descending curves revealed similarities and differences among the emulsions. The rheograms of all the emulsions started above the origin implying a positive yield stress which is desirable for the stability of semi-solid fluids (Goncalves and Maia Campos, 2009).

Power law rheological model was used to analyze the developed flow curves and calculate the hysteresis loop areas. Power law model was also used to evaluate the effect of additives on the rheological properties of emulsions (Dematrides *et al.*, 1997; Tantayotai and Pongsawatmanit, 2005; Gonclves and Maia Campos 2009). Table 1 shows the effects of NaCl concentrations on the power law rheological parameters and hysteresis loop area. The high coefficient of determination, $R^2 > 0.98$ indicated that power law model can adequately predict the rheological data. The NaCl had peculiar effects on the parameters of power law and hysteresis loop area. The mean consistency coefficient, a measure of the viscosity of the emulsion system (Tantayotai and Pongsawatmanit, 2005; Dematrides *et al.*, 1997) ranged from 30.05 to 13.61 Pas^n for the forward and 5.90 to 4.17 Pas^n for the backward curves respectively. While the flow behaviour index (n and n^i), a measure of fluid resistance to flow were in the range 0.34 to 0.41 and 0.58 to 0.61 for forward and backward curves respectively. The flow behaviour index for the forward and backward curve were less than unity indicating that all the emulsions were pseudoplastic in nature. Similar behavior was reported on the effect of NaCl and pH on the whey protein stabilized emulsion (Dematrides *et. al.*, 1997). The K and n were however relatively higher and lower respectively than those reported for protein stabilized emulsions (Dematrides *et al.*, 1997; Tantayotai and Pongsawatmanit, 2005).

The values of consistency coefficient of the forward curve were higher than the corresponding values for the backward curve while the values of the flow behavior index of the forward curve were lower than the corresponding values of backward curves indicative of structural destruction of the emulsion systems. In both cases (forward and backward curves), the consistency coefficient was observed to increase with a corresponding decrease in flow behavior. The consistency coefficients however showed significant decrease with the presence of NaCl for both forward and backward curves suggesting a decrease in emulsion viscosity. The decrease of consistency behaviour with an increase in NaCl concentration was contrary to the observation on the effect of NaCl on rheological properties of coconut oil-in-water emulsion stabilized with whey protein isolate (Tantayotai and Pongsawatmanit, 2005). For the forward curve, the decrease was obvious up to NaCl concentration of 100 mM. Emulsions containing 100, 200 and 300 mM NaCl had the mean consistency coefficient values of 13.96, 13.76 and 13.61 Pas^n and were not significantly ($p > 0.05$) different from one another. The relative difference and similarities in the emulsion with NaCl was a product of the degree of impediment caused by the various concentrations of NaCl on BGNF polymer network formation and droplet interactions in the emulsion systems. The quantification of hysteresis loop (magnitude) is detailed in Table 1. The magnitude of hysteresis loop quantified the extent of structural break down in an emulsion. The mean of the observed hysteresis loop area ranged from 771.50 to 389.9 Pas^{-1}. The magnitude of hysteresis loop area of emulsion without NaCl is significantly different ($p < 0.05$) from emulsion with NaCl. However the emulsions with NaCl showed significant and non-significant difference among themselves. The differences and similarities observed in the emulsions is a measure of relative disparities in both the BGNF matrix strength and the structural interactions in the emulsion systems. BGNF stabilized emulsion without and with 300 mM NaCl recorded the highest and lowest values, respectively. High value of BGNF emulsion without NaCl is an indication of high structural interactions and matrix strength which subsequently led to high emulsion viscosity.

Table 1. Effect of NaCl concentration on Power law parameters and hysteresis loop area[1,2]

Conc. NaCl [mM]	K [Pas^n]	n	R^2	K' [Pas^n]	n'	R^2	Hysteresis loop area [Pas^{-1}]
0	44.87 ± 5.01[a]	0.28 ± 0.01[a]	0.99	7.60 ± 0.53[a]	0.55 ± 0.34[a]	0.99	771.50 ± 44.23[a]
25	26.51 ± 1.78[b]	0.36 ± 0.02[b]	0.99	5.78 ± 0.14[b]	0.58 ± 0.01[a]	0.99	648.76 ± 21.54[ab]
50	20.33 ± 2.99[bc]	0.37 ± 0.03[b]	0.99	5.11 ± 0.18[bc]	0.57 ± 0.01[a]	0.99	563.47 ± 18.84[abc]
100	13.96 ± 2.51[c]	0.41 ± 0.03[b]	0.98	3.57 ± 0.06[bcd]	0.61 ± 0.00[a]	0.99	421.32 ± 57.67[c]
200	13.76 ± 4.09[c]	0.41 ± 0.04[b]	0.99	3.70 ± 0.04[d]	0.59 ± 0.00[a]	0.99	394.95 ± 107.41[c]
300	13.61 ± 3.28[c]	0.41 ± 0.04[b]	0.99	4.17 ± 0.05c[d]	0.58 ± 0.00[a]	0.99	389.90 ± 49.91[bc]

[1] Values are mean ± standard deviation; Means with different letters within the same column are significantly different from each other ($p < 0.05$).

[2]K refers to the consistency coefficient of the forward sweep; K' is the consistency coefficient of the backward sweep; n is the flow behaviour index of the forward sweep; n' is the flow behaviour index of the backward sweep; R^2 is the coefficient of determination between the experimental data and power law model prediction

Effect of NaCl on the steady shear decay

In order to describe the time dependent behavior observed earlier, steady shear decay method was employed. Emulsions with and without NaCl were sheared and their behaviors were compared at constant shear rate of 50 s^{-1}. Figure 2 shows the effect of shearing time on the viscosity of the emulsions containing different concentration of NaCl measure at a constant shear rate of 50 s^{-1}. All the emulsions showed a time dependent thixotropic characteristics as there was a noticeable decrease in the viscosity with increased shearing time. In addition, different NaCl contents in the emulsions had altered thixotropic properties of the emulsion in a dissimilar manner. The viscosity of the emulsions with and without NaCl at initial and final time of shearing can be visualized from the ordinate of the viscosity-shearing time graph (Figure 2).

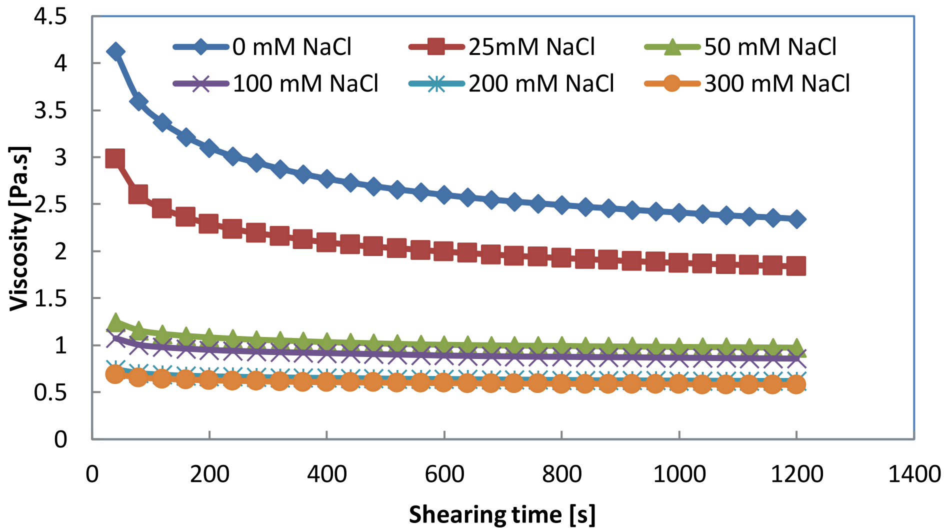

Figure 2. **Effect of NaCl on time dependent characteristics of optimized emulsion at 50 s^{-1}**

The figure suggested that the presence of NaCl had reduced the viscosity of the emulsions relative to emulsion without NaCl. The curve of the emulsion with no NaCl was at the top while emulsions containing 25, 50, 100, 200 and 300 mM NaCl were below.

Table 2. Effect of NaCl concentrations on Weltman model parameters[1,2]

Concentration of NaCl [mM]	- B [Pa]	A [Pa]	R^2
0	24.17 ± 1.64[a]	285.70 ± 13.11[a]	0.98
25	14.95 ± 0.22[b]	195.95 ± 1.44[b]	0.97
50	3.63 ± 0.21[c]	73.83 ± 6.88[c]	0.97
100	2.92 ± 0.08[c]	59.05 ± 7.09[d]	0.98
200	1.63 ± 0.07[d]	42.42 ± 1.82[e]	0.98
300	1.49 ± 0.12[d]	39.47 ± 2.05[e]	0.99

[1]values are mean ± standard deviation; Means with different letters within the same column are significantly different from each other ($p < 0.05$).

[2] A equals to the initial shear rate of Weltman model; B is the extent of structural break down of Weltman model; R^2 is the coefficient of determination between the experimental data and Weltman model prediction

Although the highest changes in viscosity between the initial and final time of shearing was found in the emulsion without NaCl, emulsion containing 25 mM NaCl showed the highest change in viscosity among the emulsions containing various concentrations of NaCl. However, after 1200 seconds of shearing, emulsion with 25 mM NaCl had the highest apparent viscosity among other BGNF emulsions containing NaCl. The observed influence of NaCl on time dependent characteristics in the emulsions was modeled using Wetman model. Table 2 shows the Weltman model parameters at a constant shear rate of 50 s^{-1} as a function of NaCl concentrations. The high coefficient of determination (>0.97) suggested that Weltman model was able to represent the time-dependent rheological data. Table 4 showed that both parameters (A and B) of Weltman model were influenced by different NaCl concentrations. The mean of Weltman model parameter A ranged from 24.17 to 1.49 Pa and parameter B was from 285.70 to 39.47 Pa for emulsion without NaCl to 300 mM NaCl. Emulsion without NaCl was significantly different ($p < 0.05$) from emulsions with NaCl. The highest and the lowest value of parameter A and B belonged to emulsion without NaCl and emulsion containing 300 mM NaCl respectively. However a comparison among emulsions prepared with different concentrations of NaCl suggested that emulsion containing 25 mM NaCl had the highest values of Weltman model parameters A and B which can be interpreted as high emulsion stability due to its relatively higher viscosity.

Effect of NaCl on the viscoelastic properties (storage and loss moduli)

Figures 3 shows the frequency sweep obtained for emulsion formulated with 0, 25, 100, 200 and 300 mM NaCl respectively. Both the emulsions without and with NaCl exhibited both the G' and G''.

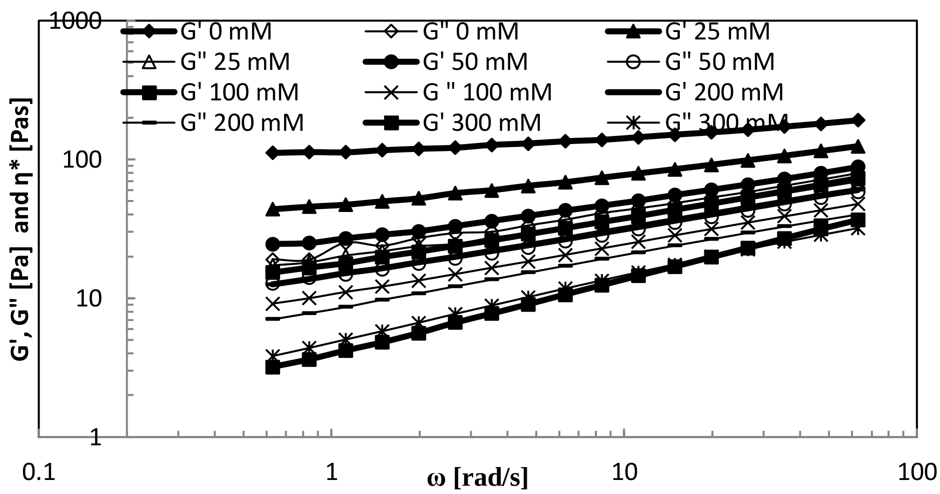

Figure 3. Storage (G') and loss (G") moduli as a function of angular frequency during dynamic oscillatory tests of sunflower oil-in-water emulsion containing various concentration of NaCl.

Both G' and G" showed significant dependence on the frequency and were increased with increase in frequency for the emulsions with NaCl. Emulsion without NaCl showed less dependence on frequency and tended to form a plateau at high frequency. Emulsions containing 0 mM, 25 mM, 50 mM, 100 mM and 200 mM NaCl showed a solid-like behaviour at all the studied frequencies where G' dominated and was higher than the G'' curve and tended to show a constant limiting value. This implied predominance in elastic characteristic over viscous behaviour at the frequency range investigated suggesting that the emulsions were weak gels. The spectrum of emulsion with 300 mM NaCl showed that the G" was higher than G' at the lower frequencies which was an indication of liquid character at a very low frequency. There was a cross over at higher frequency of about 19.86 rad/s and G' was observed to be higher than G" there by showing a solid-like behaviour at higher frequency. This behaviour is typical of viscoelastic material.

The effect of NaCl concentrations was noticeable on the material functions. Both G' and G'' decreased with increase in NaCl concentrations. Decreased G' and G" was as a result of increased instability in the emulsions as the concentrations of the NaCl increased resulting into less interactions and consequent emulsion instability. The decrease in material function as the concentration of NaCl increased was a result of impediment posed by the NaCl to BGNF polymer network formation. The NaCl reduced the BGNF matrix strength necessary for emulsion formation. This result is however, contrary to the report of Martınez *et al*. (2007) on the effect of salt content on the rheological properties of salad dressing-type emulsions stabilized by emulsifier blends. They reported an increase in viscoelastic functions with increase in salt contents.

Effect of NaCl on the rheological properties of emulsion with regard to compliance and recoverable strain

Figure 4 shows the compliance (J) against time (s). A load of 0.5 Pa was imposed on the structure of the emulsions in the first part of the experiment for 500 s while the second part involved sudden removal of the load and compliance was monitored for the next 500 s. All emulsions with and without NaCl showed similar viscoelastic characteristics during creep and recovery phases. For instance, J increased steadily when a stress of 0.5 Pa was imposed on all the emulsions during the creep stage and the elastic component of the deformation recovered instantaneously when the load was removed. The emulsion without NaCl recorded the lowest while emulsion containing 300 mM NaCl recorded the highest J.

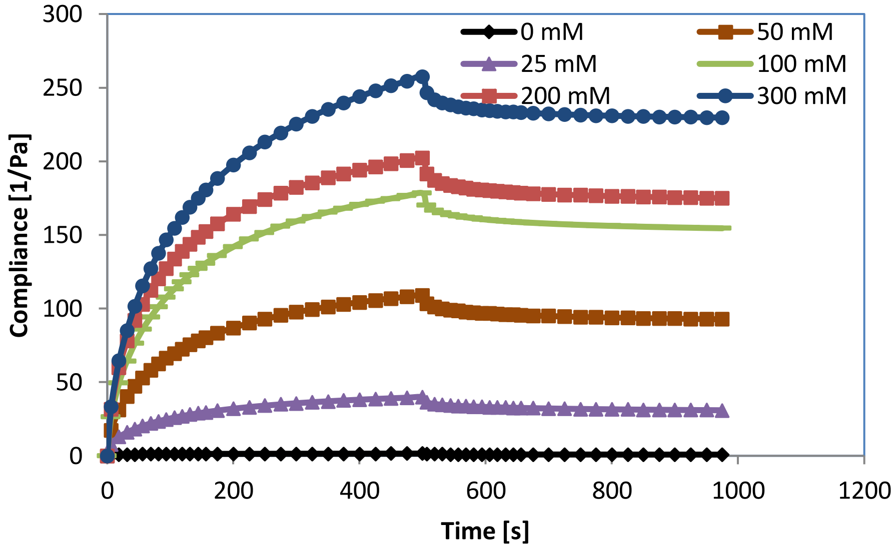

Figure 4 **Creep and recovery curves of emulsions containing various concentrations of NaCl**

The high J for 300 mM NaCl emulsion indicated a negligible instantaneous elastic compliance and implied that the network of the emulsion structure is weak and less rigid. Emulsions with lower J possess stronger structural interactions (high rigidity) hence gave small deformation when the stress was imposed on them. NaCl had profound influence on the compliance. Increase in NaCl concentrations (Figure 5) increased J. This was as a result of decreased structural formation (droplet – droplet interaction) as NaCl concentration increased and this subsequently decreased emulsion rigidity. However, among the emulsions containing NaCl, emulsion with 25 mM NaCl had the lowest J. Table 3 shows the effect of NaCl concentrations on the recoverable strain, Q (t)% of the studied emulsion. Q (t)% indicated how much percentage of the structure was able to recover when the load was withdrawn from the emulsions and hence it was a measure of the elasticity of the emulsion. Increased Q (t)% can therefore be linked to increased elasticity of the emulsions. The mean of Q (t)% ranged between 10.82 to 46.15% for all the emulsions. Increased concentration of NaCl in the BGNF matrix had a profound significant decrease ($p < 0.05$) on the elasticity. The emulsion containing 300 mM NaCl, had the lowest Q (t)% indicating that this emulsion had the lowest elasticity and stability among the emulsions. Emulsion with 25 mM NaCl, recorded the highest elasticity among emulsions with NaCl.

Table 3. Effect of NaCl concentration on the recoverable strain[1,2]

NaCl concentration [mM]	Recoverable strain Q(t)%

0	46.15 ± 1.49^{d}
25	22.38 ± 1.53^{c}
50	14.99 ± 0.59^{b}
100	13.34 ± 0.35^{b}
200	13.50 ± 0.55^{b}
300	10.82 ± 0.58^{a}

[1] Values are mean ± standard deviation; Mean values with different letters within the same column are significantly different from each other ($p < 0.05$).
[2] Q (t)% equals the recoverable strain

Conclusion
The relative impediments caused by the presence of NaCl to the BGNF network formation during the continuous phase preparations brought about significant difference to the characteristics of emulsions. The presence of NaCl in the BGNF matrix showed a significant reduction in emulsion properties relative to emulsion without NaCl. However the presence of NaCl at 25 mM is thought not to cause much severity to both BGNF polymer strength and structural interactions. Although both the emulsions with and without NaCl had similar rheological properties, the influence of NaCl on the BGNF matrix appeared to reduce some characteristics such as thixotropy, pseudoplasticity and viscoelasticity. The changes in the microstructure of the emulsions due to the presence of NaCl in the BGNF polymer network had manifested as differences in the rheological properties such as significant reduction in apparent viscosities and viscoelasticity which could account for the disparities in their stabilities.

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