

CHEMICAL ENGINEERING | RESEARCH ARTICLE

# Physical stability characteristics of sunflower oil-in-water emulsion containing sodium chloride, stabilized by gelatinized bambara groundnut flour

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# Physical stability characteristics of sunflower oil-in-water emulsion containing sodium chloride, stabilized by gelatinized bambara groundnut flour

Oladayo Adeyi<sup>1\*</sup>, Daniel I.O. Ikhu-Omoregbe<sup>2</sup> and Victoria Adaora Jideani<sup>3</sup>

**Abstract:** The influence of sodium chloride salt (NaCl) concentrations on the physical stability of sunflower oil (SFO)-in-water emulsions (40 w/w% SFO) stabilized by 7 w/w% bambara groundnut flour (BGNF) was investigated. Oil droplet sizes and emulsion microstructure were measured microscopically. Physical stability was studied using an optical analyzer, Turbiscan MA 2000, by observing changes in backscattering flux (%) at 20°C. NaCl significantly affected ( $p < 0.05$ ) emulsion stability of BGNF-stabilized emulsion. Increased NaCl in the emulsion increased droplet size and physical instability of BGNF-stabilized emulsions. The results indicated that the stability of BGNF-stabilized emulsion can be controlled and manipulated using NaCl. Emulsion destabilization involving oil droplet agglomeration is prevalent in all the studied SFO-in-water emulsions and emulsion microstructures were significantly affected by the presence of NaCl in gelatinized BGNF matrix.

**Subjects:** Food Additives & Ingredients; Food Chemistry; Food Engineering; Chemical Engineering

**Keywords:** bambara groundnut; oil-in-water emulsion; physical stability

### ABOUT THE AUTHORS

Oladayo Adeyi obtained his B.Tech degree from Ladoko Akintola University of Technology and M. Sc. from University of Ibadan in Nigeria. He then worked for 3 years as a lecturer at Bowen University Nigeria. After that, he moved to South Africa for his postgraduate study and obtained his PhD degree from the Department of Chemical Engineering at the Cape Peninsula University of Technology in 2015. He advanced his career at Landmark University, Omu-Aran, Nigeria after his PhD program. His research interests cover bioprocessing, food emulsion formulation, stability and rheological characterizations.

### PUBLIC INTEREST STATEMENT

Natural stabilizing composition in food systems is becoming increasingly popular because of its numerous health implications. Hence, one of the many challenges in food industry is to find natural stabilizers of desired functionalities to replace synthetic stabilizers because consumers are demanding for more natural food products. Gelatinized bambara groundnut flour has recently been shown to possess admirable potential to stabilize food emulsions and oil-in-water emulsions stabilized by gelatinized bambara groundnut flour to possess desirable characteristics which may find applications in food industries. However, since most food emulsions contain sodium chloride during formulation stage, emulsions containing sodium chloride that are stabilized by gelatinized bambara flour need to be characterized in order to understand its behavior during product and process design.

## 1. Introduction

Emulsion forms the basis of most food and delivery systems and their properties define their eventual applications. An emulsion is a biphasic, metastable coarse dispersion of two immiscible materials, usually liquids (typically oil and water), that produces a semisolid (Sarker, 2013). Among important emulsion properties is emulsion stability. Emulsion stability is the ability of the emulsion to resist changes over time and ultimately determines the shelf-life of emulsion. Some of the factors having profound effects on the properties of food emulsions are the aqueous phase compositions (Binks & Lumsdon, 2000), salts (Aronson & Petko, 1993; Martinez, Riscardo, & Franco, 2007), temperature (Tarko & Tuszyński, 2007) and aging (Gonçalves & Maia Campos, 2009).

An increasingly growing area in food emulsion technology research is finding new alternatives for improving the stability and rheological properties of emulsions. The effectiveness and functionalities of synthetic surfactants such as acyl lactylates, dioctyl sodium sulfosuccinate, propylene glycol monoesters, sucrose esters and sorbitan esters have made them find applications as food emulsifier and modifiers in food applications (Akoh & Swanson, 1994). There have been reports of polyglycerol fatty acid ester, polyoxyethylene sorbitan monolaurate (Tween 20), and sucrose fatty acid ester, sucrose palmitate (Partal, Guerrero, Berjano, Muñoz, & Gallegos, 1994), dioctyl sodium sulfosuccinate (Higuchi, Okada, & Lemberger, 1962) and polyglycerol esters of fatty acids (Tan & Nakajima, 2005) as food emulsifiers. 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, Leser, Sher, & McClements, 2013) and challenge in food industries.

The nutritional composition of bambara groundnut (BGN) indicates its potential as a natural food emulsifier/stabilizer and gelatinized BGN flour (BGNF) dispersion (GBGNFD) has been reported to stabilize sunflower oil (SFO)-in-water emulsion (Adeyi, Ikhu-Omoregbe, & Jideani, 2014). BGN is an underutilized African legume 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 & Jideani, 2013). The high percentage of protein and carbohydrate contents made BGN to have high potential as main emulsifier/stabilizer in food emulsions.

SFO-in-water emulsion stabilized by gelatinized BGNF is an emulsion system that may find applications in food industries because of its pseudoplastic, viscoelastic and thixotropic 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 salt on the properties of SFO-in-water emulsion stabilized by gelatinized BGNF to get a better understanding for product and process development in food industries. Therefore, the objective of this study was to investigate the physical stability characteristics of SFO-in-water emulsions that were stabilized with gelatinized BGNF containing various concentrations of sodium chloride salt. This is necessary to understand the behavior of such emulsion system during product design and for the future adoption of BGNF as a natural stabilizer in food industry.

## 2. Materials and methods

### 2.1. Materials

Dried BGN seeds of brown variety were purchased from Triotrade Gauteng CC, South Africa. The seeds were washed and dried at 50°C for 48 h by using cabinet drier (Model: 1,069,616). The dried seeds were milled into flour using a hammer mill and screened through 90 µm sieve to give BGNF. A commercial brand (Ritebrand) of 100% 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.

## 2.2. Emulsion preparation

Sodium chloride solution of various concentrations (25–300 mM) was prepared and used to prepare the continuous phase of the emulsions. Emulsions were prepared from a dispersed phase and a continuous phase. The dispersed phase consisted of SFO and continuous phase was gelatinized 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 min with constant stirring. The resulting GBGNFDs 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 min at the speed of 11,000 r/min.

## 2.3. Quantification of droplet sizes and distributions of emulsion by image analysis

Microstructure of the emulsions immediately after emulsion preparation was analyzed in terms of droplet size and droplet size distribution according to the method of Adeyi et al. (2014). Each emulsion was diluted with Milli-Q water at a ratio of 1:5 (w/w) in order to avoid overlapping and agglomeration of oil droplets which can affect further image analysis and processing. Droplet sizes were determined from the images of the oil-in-water emulsion obtained with a light microscope (Ken-A-vision). Emulsion samples were poured onto microscope slides and covered with glass cover slips and visualized using ×40 objective lens. The microscope focus and the light intensity were carefully controlled and optimized in order to obtain the sharpest possible boundaries between the oil droplets and the surrounding GBGNFD. The images were captured with a digital camera mounted on the microscope. Image processing and further analysis were carried out using a public domain software image J v1.36b (Caubet, Guer, Grassil, Omari, & Normandin, 2011; Perrechil & Cunha, 2010). The diameters of the oil droplets were measured one by one by an operator (Tcholakova, Denkov, & Danner, 2004). A substantial number of droplets ( $N = 1,000$ ) were counted in order to obtain statistical estimate of the oil droplet diameters and oil droplet size distribution in each sample. Droplet size distributions were generated by grouping the droplets into classes belonging to a common interval. Droplet size frequency distributions were computed using MS Excel (Microsoft™ Excel 2007) (Bellalta, Troncoso, Zuniga, & Aguilera, 2012). Oil droplet sizes were obtained in terms of volume–surface mean diameter ( $d_{3,2}$ ) and equivalent volume–mean diameter ( $d_{4,3}$ ). The volume–surface mean diameter ( $d_{3,2}$ ) and equivalent volume–mean diameter,  $d_{4,3}$ , were calculated using the following equations, respectively.

$$D_{3,2} = \frac{\sum n_i d_i^3}{\sum n_i d_i^2} \quad (1)$$

$$D_{4,3} = \frac{\sum n_i d_i^4}{\sum n_i d_i^3} \quad (2)$$

where  $n_i$  is the number of droplets with diameter  $d_i$  ( $\mu\text{m}$ ).

## 2.4. Optical characterization of emulsion stability

The stability of oil-in-water emulsions stabilized with BGNF was monitored using Turbiscan MA 2000 (Formulation, France) according to Adeyi et al. (2014). BGNF-stabilized emulsion (6 mL) was introduced in a cylindrical glass cell and inserted into Turbiscan MA 2000. The optical reading head of the machine scanned the whole length of the sample and acquired both the transmission and backscattered data every 40  $\mu\text{m}$  and 30 min for 6 h. The transmission and backscattering curves

generated provided transmission and backscattered light flux in percentage (%) relative to the internal standard of the machine as a function of sample height. Both the transmission and backscattering fluxes were dependent on the particle mean diameter,  $d$ , and volume fraction,  $\phi$ , of the particles according to the Equations (3)–(6), respectively (Camino & Pilosof, 2011).

$$T = T_o e^{-\frac{2d}{r_i}} \tag{3}$$

$$l^* = \frac{2d}{3\phi Q_s} \tag{4}$$

$$BS = \frac{1}{\sqrt{l^*}} \tag{5}$$

$$l^* = \frac{2d}{3\phi(1-g)Q_s} \tag{6}$$

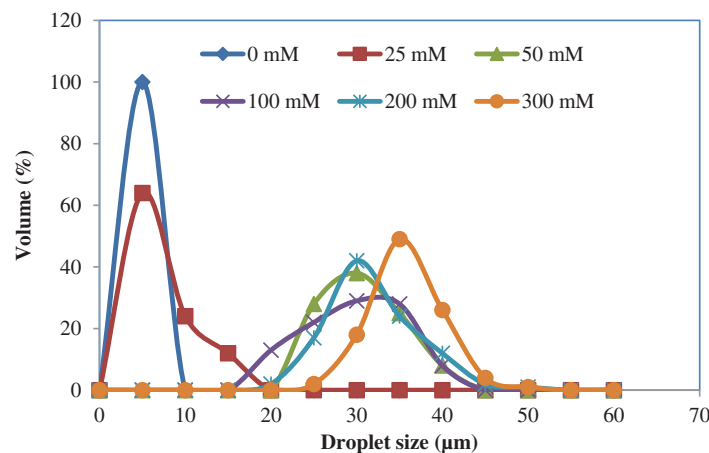
where  $T, T_o, r_i, l^*, d, \phi, BS$  are transmitted fluxes, transmittance of the continuous phase, measurement cell internal radius, photon mean free path, particle mean diameter, particle volume fraction, backscattered flux, respectively.  $Q_s$  and  $g$  are optical parameters given by Mie theory. The analysis of the emulsion stability was carried out as a variation of backscattering profiles over time because of the opaque nature of the emulsion nil transmission flux. The stability or instability of the dispersion was observed and evaluated by conducting repeated multiple scans over time, each one providing a curve and all curves were overlaid on one graph to show stability or otherwise of the dispersion over time.

### 3. Results and discussion

#### 3.1. Effect of NaCl on droplet size distribution

Figure 1 shows the droplet size distributions of emulsion (7% [w/w] BGNF and 40% [w/w] SFO) containing a range of concentration of NaCl (0–300 mM). All the droplet size distributions presented a nearly Gaussian shape with few secondary populations. This indicated that the droplets were polydispersed in nature. The presence of NaCl at various concentrations in the BGNF emulsions affected the width and population of the oil droplets in a dissimilar manner. When compared with the emulsion without NaCl, the width of the distribution shifted to the right implying an increase in oil droplet size. Table 1 shows the effect of NaCl concentrations on the oil droplet size of the emulsion. The volume surface mean diameter  $d_{3,2}$  which provided information where most particle fell (Koocheki & Razavi, 2009), ranged between 3.45 and 34.48  $\mu\text{m}$ , while  $d_{4,3}$ , the

**Figure 1.** Droplet size distribution of dispersed phase particles in emulsion formulated with 7% (w/w) BGNF and 40% (w/w) SFO containing various concentrations of NaCl.



**Table 1. Effect of NaCl on oil droplet size.<sup>1,2</sup>**

Con. NaCl (mM)	$d_{3,2}$ ( $\mu\text{m}$ )	$d_{4,3}$ ( $\mu\text{m}$ )
0	$3.45 \pm 0.10^a$	$3.66 \pm 0.11^a$
25	$8.72 \pm 0.42^b$	$10.14 \pm 0.04^b$
50	$29.34 \pm 0.49^c$	$29.99 \pm 0.41^c$
100	$29.68 \pm 0.82^c$	$30.57 \pm 0.51^c$
200	$31.31 \pm 1.11^d$	$32.39 \pm 0.87^d$
300	$34.48 \pm 0.69^e$	$35.06 \pm 0.13^e$

<sup>1</sup>Values  $\pm$  standard deviation; means with different letters within the same column are significantly different from each other ( $p < 0.05$ ).

<sup>2</sup> $d_{3,2}$  refers to the volume–surface mean diameter of the emulsions;  $d_{4,3}$  is the equivalent volume–mean diameter of the emulsions.

equivalent volume–mean diameter which is related to changes in droplet size involving destabilization process (Camino & Pilosof, 2011), ranged between 3.66 and 35.06  $\mu\text{m}$ . The range of  $d_{4,3}$  obtained from this work was relatively higher than those reported on the effect of NaCl concentrations (0–500 mM) on the particle size of biopolymer-stabilized emulsions (Tarrega, Duran, & Costell, 2004). Increased in the NaCl concentrations had an observable negative effect on the initial microstructure of the emulsions by increasing the oil droplet size. Both  $d_{3,2}$  and  $d_{4,3}$  increased significantly ( $p < 0.05$ ) with increased NaCl concentration. Various articles have reported the influence of NaCl on droplet size and emulsion stability which largely depended on the nature of the emulsion system in question. As an example, similar observation of increase in oil droplet size with increase in NaCl concentration for emulsion stabilized with coconut skim milk protein isolate, coconut skim milk protein concentrate and whey protein isolate (WPI) and their observation was explained in terms of electrostatic interactions between the emulsion droplets (Gu, Decker, & McClements, 2005). On the contrary, the microstructure of low in fat oil-in-water emulsion stabilized with polysaccharides (potato starch and xanthan gum) containing salt at 0 and 0.5 M showed no difference in oil droplet distribution and size (Quintana, Califano, Zaritzky, & Partal, 2002). Similarly, the addition of NaCl at 1% or 2–0.4% xanthan gum-stabilized emulsions did not cause any change in mean droplet size upon aging (Yilmazer & Kokini, 1992). The  $d_{4,3}$  of emulsions stabilized with WPI also showed an appreciable increase at NaCl concentration of 200 mM and greater with NaCl concentrations having little effect on the emulsion stabilized by gum arabic (GA) and modified starch (MS) (Tarrega et al., 2004). However, increased NaCl concentration from 0 to 25 mM in the BGNF-stabilized emulsion showed a nearly doubled increase in oil droplet size in addition to noticeable significant increase as NaCl increased from 50 to 300 mM.

Emulsion containing 25 mM NaCl had the minimum  $d_{3,2}$  and  $d_{4,3}$  with corresponding values of 8.72 and 10.14  $\mu\text{m}$ , respectively. Smaller oil droplets have been said to contribute to greater emulsion stability while the larger the mean droplet size the higher the creaming rate (Lim, Wong, Law, Samyudia, & Dol, 2015), coalescence rate and the probability of flocculation (Stewart & Mazza, 2000). When compared with other systems that were stabilized mainly by polysaccharides such as the GA, MS, potato starch and xanthan gum, the influence of NaCl was very noticeable and deleterious on the oil droplet size of BGNF-stabilized emulsions. This could be due to the method of incorporation of NaCl into the BGNF-stabilized emulsions. BGNF has been reported to be sensitive to different kinds of electrolytes and its gelation property has been found to respond differently to the effect of NaCl (Aremu, 2008). During the course of continuous phase preparation in this research, aqueous phase containing NaCl at various concentrations was used to gelatinize the BGNF prior to emulsification. NaCl that was present in the aqueous phase might probably have interfered with the polysaccharides network negatively during formation thereby reducing the emulsion forming and stabilizing properties of gelatinized BGNF. It has been reported that the presence of salt at some concentration during gelatinization may cause denaturation of seed protein and probable neutralization of charges stabilizing gel formation (Giarni & Bekebaib,

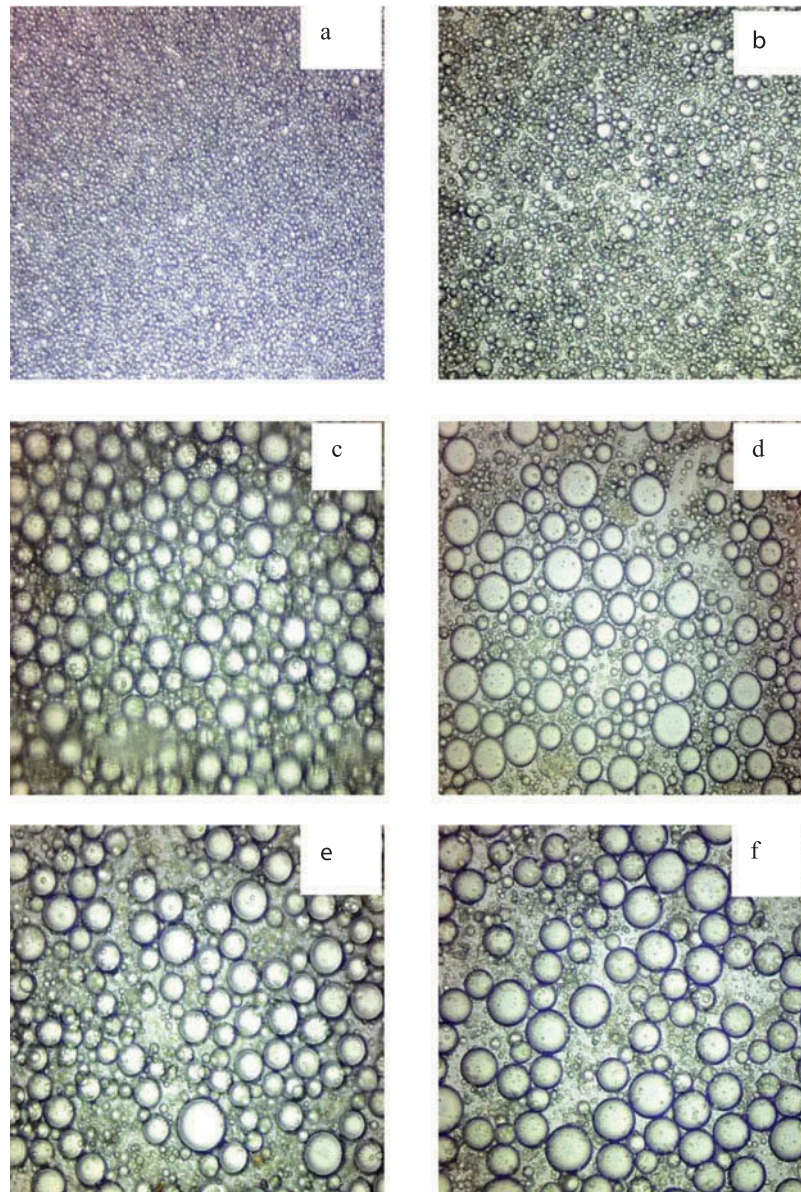


1992). However, NaCl at a level of less than 25 mM seemed to have caused less harm to the polymer network while NaCl concentration of more than 50 mM greatly hindered the emulsion formation and promoted large oil droplet.

### 3.2. Effect of NaCl on the microstructure

Figure 2 shows the effect of NaCl on the microscopic images of the emulsion (7% [w/w] BGNF and 40% [w/w] SFO). The images are the microstructure of the recently prepared emulsions containing various concentrations of NaCl (0–300 mM). The images showed that the droplets are polydispersed systems. In comparison with the emulsion without NaCl (Figure 2(a)), the effect of NaCl concentration on the microstructure was noticeable and deleterious. Increased NaCl concentration from 0 to 25 mM resulted in relatively fewer large oil droplet. The microstructure of the emulsion containing 25 mM NaCl was the least affected among emulsion systems containing NaCl. Increasing the concentration of NaCl in the gelatinized BGNF matrix resulted into increased size of the oil droplets in the resulting emulsions. This was indicative of

**Figure 2. Micrographs ( $\times 40$  magnification) of 40% SFO and 7% BGNF emulsions containing (a) 0 mM NaCl (b) 20 mM NaCl (c) 50 mM NaCl (d) 100 mM NaCl (e) 200 mM NaCl (f) 300 mM NaCl.**



relative impediment caused by the presence of NaCl to BGNF polymer network formation and droplet-droplet interactions. The aggregated droplets that stood side by side could have coalesced to form bigger oil droplets as a result of the effect NaCl present in the gelatinized BGNF matrix. The extent of aggregation and creaming has been reported to increase with an increase in NaCl concentration for an oil-in-water emulsion stabilized by coconut skim milk protein (Gu et al., 2005). The micrographs of emulsions with 50 mM and above presented a higher number of bigger oil droplets relative to smaller ones and showed areas of unoccupied aqueous phase. The presence of big oil droplets is an indication of high tendencies of the emulsions to destabilize faster relative to the emulsion without NaCl. However, not a very clear difference was observed among the microstructures of the emulsions containing 50, 100, 200 and 300 mM NaCl.

### 3.3. Effect of NaCl on the storage stability of emulsion

All the emulsions showed similar destabilization mechanism. Figures 3 and 4 are the Turbiscan profiles of emulsions containing 0, 25 and 50 mM NaCl and 100, 200 and 300 mM NaCl, respectively, scanned at 30 min interval for 360 min stored at 20°C. The profiles were presented in both the normal Turbiscan mode (left) and the reference mode (right). In the reference mode, the first profile of all the emulsions was used as a reference profile, and its backscattering flux was represented as 0% relative to other profiles. The normal mode showed the backscattering flux (%) of all the profiles against the tube length. The first scan was the initial backscattering flux  $BS_{AVO}$  (%), and it gave information about the microstructure of the freshly prepared emulsion. The  $BS_{AVO}$  (%) was directly related to the number of the oil droplets in an emulsion system. The  $BS_{AVO}$  (%) of the emulsion containing between 0 and 300 mM NaCl is detailed in Table 2.

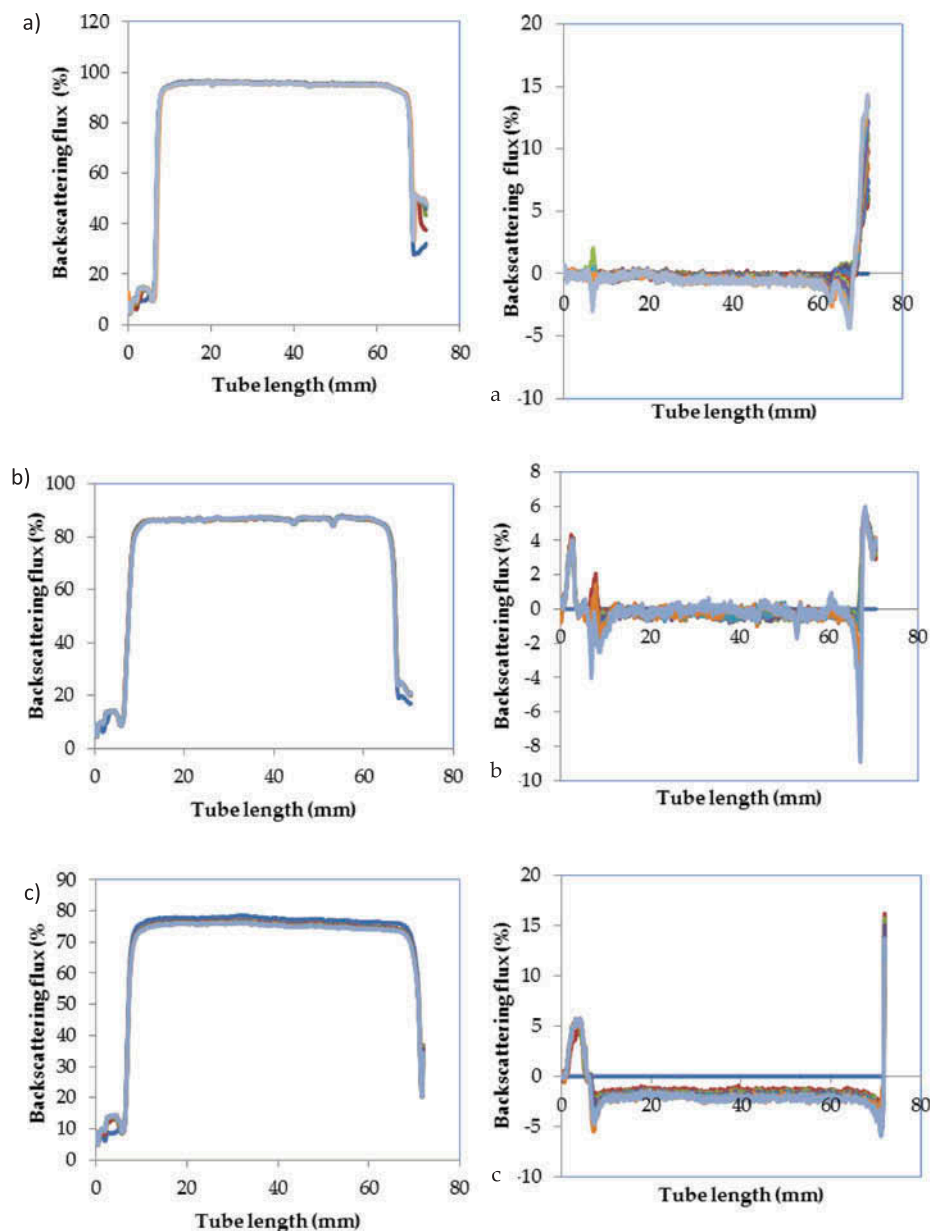
The mean of  $BS_{AVO}$  (%) ranged from 95.29% to 69.00% for emulsions containing 0–300 mM NaCl. The NaCl concentration had significant influence on the  $BS_{AVO}$  (%). NaCl concentration decreased the  $BS_{AVO}$  (%) value until NaCl concentration of 100 mM was attained. There was, however, no significant difference in the  $BS_{AVO}$  (%) of emulsions with NaCl concentrations of 100, 200 and 300 mM. This could be as a result of comparable impediment NaCl of 100 mM and above imposed on the emulsion forming ability of gelatinized BGNF. When compared with other formulations containing NaCl, emulsion with 25 mM had the highest  $BS_{AVO}$  (%). As mentioned earlier, the presence of NaCl in the continuous phase during gelatinization of BGNF dispersions might have impeded the polymer network formation which affected the emulsion forming properties of gelatinized BGNF. This process might have hindered emulsion formation which consequently was observed as lowered backscattering flux relative to emulsion without NaCl. The relative increase or decrease of the initial backscattering flux (%) was therefore an indication of the emulsion forming ability of the BGNF dispersions containing different concentration of NaCl and also presented a measure of the microstructure of the resulting emulsions. Therefore, emulsion system with 25 mM NaCl seemed to form BGNF matrix with a firmer film thickness which was responsible for a better emulsion formation relative to other NaCl containing emulsions. Emulsions with 100 mM NaCl and greater seemed to possess similar BGNF polymer matrix.

The result of the reference mode showed relative changes in the Turbiscan profile of the emulsions over time. The backscattering flux decreased along the whole length of the tube with time and there was presence of a peak at the bottom region of the tube (0–10 mm) indicative of oil droplet aggregation (flocculation or coalescence) and creaming phenomena, respectively. Decrease in the backscattering flux was as a result of an increase in the oil droplet size which correspondingly caused the mean path of photon ( $l^*$ ) to increase because of an increase in the average distance between the oil droplets.

Figure 5 showed that NaCl concentrations had dissimilar effects on emulsion stability over time (kinetics). The presence of NaCl in the emulsions at all concentrations had a negative effect on emulsion stability. NaCl in the BGNF-stabilized emulsion systems tended to decrease the average backscattering flux relative to emulsion without NaCl and this invariably implied a decrease in

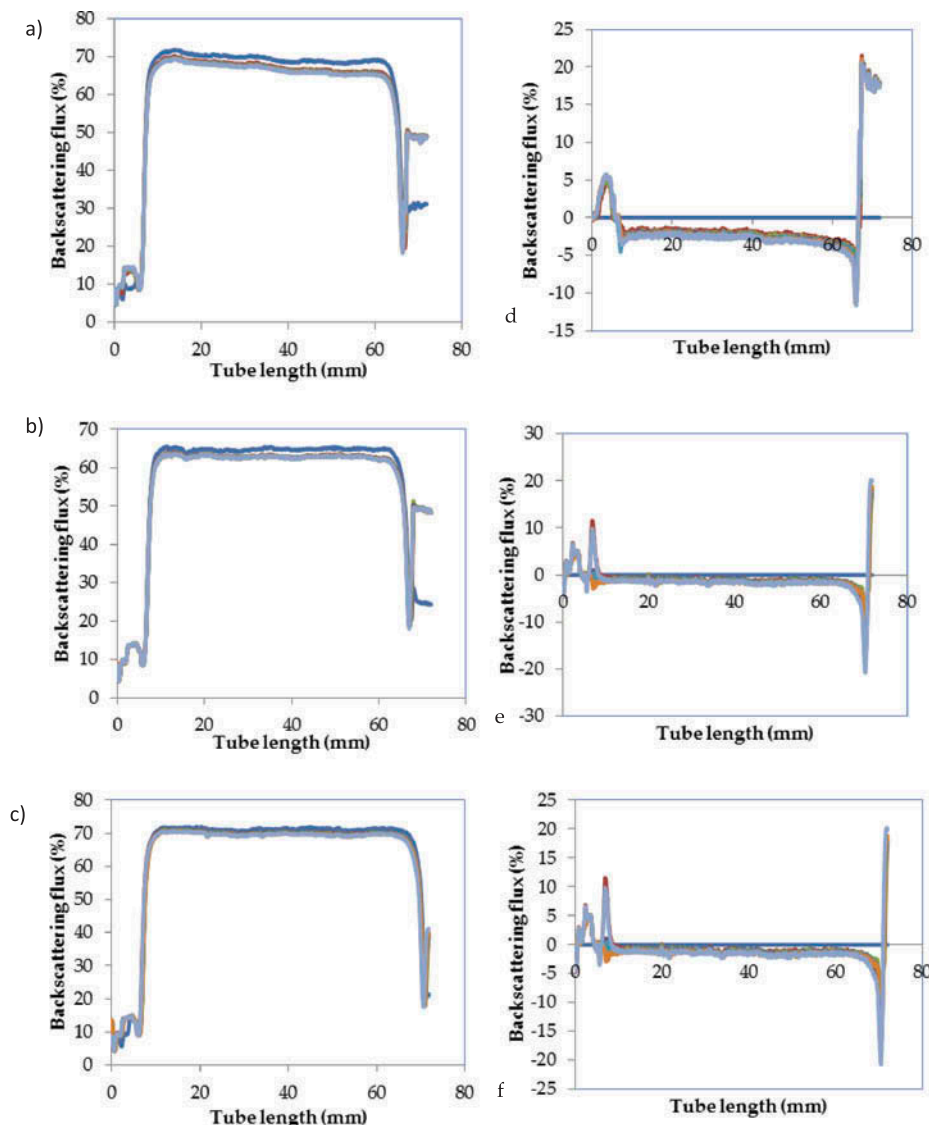


**Figure 3. Changes in the backscattering profile (BS%) as a function of sample height during storage of emulsion containing (a) 0 mM NaCl (b) 25 mM NaCl (c) 50 mM NaCl.**



emulsion stability. NaCl has been reported to have various noticeable effects on the emulsion stability and this largely depended on the compositions of emulsion systems. As an example, during the investigation of the effect of NaCl contents on the properties of salad dressing-type emulsion which were stabilized by emulsifier blends of protein origin, it was reported that an increase in salt concentration led to a significant increase in emulsion stability (Martinez et al., 2007). Similarly, it was observed that a salad dressing emulsion type with low NaCl content of 1% was found to be less stable relative to a system with higher NaCl content (4%) (Stewart & Mazza, 2000). The observation was explained based on the inability of egg protein to act as a good emulsifier at low NaCl concentration. The investigation of the effect of NaCl concentrations on the emulsions stability of emulsion systems stabilized by WPI, GA and MS was also conducted (Tarrega et al., 2004). The authors reported emulsion instability of WPI-stabilized emulsion at higher salt concentration of ( $\geq 200$  mM NaCl) and stability of GA and MS emulsions at all NaCl concentrations. BGNF-stabilized emulsion containing 25 mM NaCl, however, showed highest

**Figure 4. Changes in the backscattering profile (BS%) as a function of sample height during storage of optimum emulsion containing (a) 100 mM NaCl (b) 200 mM NaCl (c) 300 mM NaCl.**



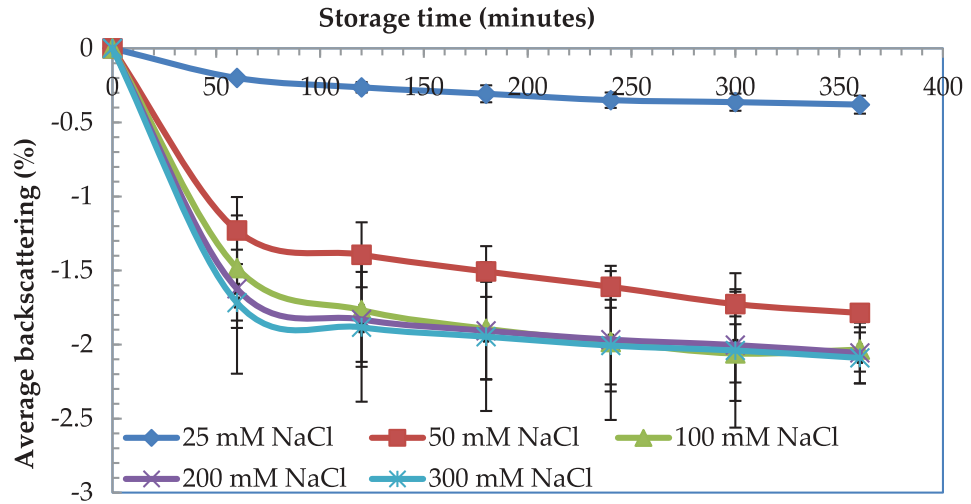
**Table 2. Effect of NaCl concentration on initial backscattering**

NaCl (mM)	Initial backscattering ( $BS_{AV0}$ ) (%)
0	$95.29 \pm 0.01^a$
25	$88.51 \pm 0.01^b$
50	$78.65 \pm 0.01^c$
100	$69.16 \pm 0.02^d$
200	$69.33 \pm 0.03^d$
300	$69.00 \pm 0.02^d$

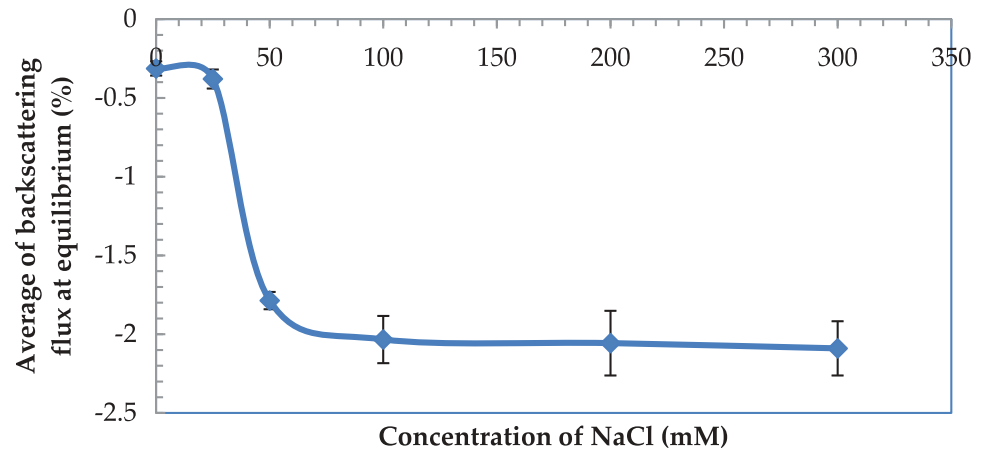
<sup>1</sup>Mean values with different letters within the same column are significantly different from each other ( $p < 0.05$ ).

stability followed by 50 mM NaCl. The stability of emulsions containing 100, 200 and 300 mM NaCl could not be clearly resolved in the destabilization kinetics profile (Figure 5) beyond 100 min of study. This is because results were marred with high standard deviations. The emulsion systems

**Figure 5. Variation in backscattering in the 20–40 mm zone monitored over 360 min for stored in quiescent condition at 20°C (emulsion containing different concentrations of NaCl).**



**Figure 6. Effect of NaCl on emulsion stability (average backscattering flux at equilibrium state).**



became relatively unstable as NaCl concentration increased. This could be directly related to the extent of impediment caused by different NaCl concentrations to polymer network formation during the preparation of the continuous phase. The backscattering flux (%) at equilibrium was plotted against NaCl concentration in order to analyze emulsion stability at equilibrium time. The equilibrium backscattering flux (%) is the final backscattering flux attained at the equilibrium time. All of the studied emulsions reached equilibrium at about 360 min (Figure 5). Therefore, the backscattering flux (%) values at 360 min were plotted against the respective NaCl concentrations. The graph of the equilibrium backscattering flux (%) against concentration (Figure 6) showed clearly that NaCl concentrations affected the average equilibrium backscattering flux (%). Emulsion without NaCl remained the most stable within the studied time interval. However, emulsion formulated with 25 mM NaCl was the most stable among emulsions containing NaCl. Emulsion containing 100, 200 and 300 mM NaCl showed similar destabilization profile and therefore their equilibrium backscattering values (%) were not judged to be different from one another.

#### 4. 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 stability of the emulsion seemed to be dependent on the microstructural properties

of the emulsion. Emulsion that contained the least concentration (25 mM) had the least oil droplet size, high  $BS_{AVO}$  (%) and flocculated microstructure relative to other emulsions with NaCl. The difference in properties could be a measure of extent of relative imposition of NaCl on BGNF structuration and emulsification. 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 emulsion formation.

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#### Cover Image

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