



## RHEOLOGICAL PROPERTIES OF MALTED AND/OR FERMENTED FARO 44 RICE PLUS SOYBEAN-BASED COMPLEMENTARY FOODS

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### ARTICLE INFORMATION

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### ABSTRACT

High nutrient density foods are required by infants for optimal healthy growth. This can be achieved by an established food processing technology. So, the study investigated the rheological properties (concentrations, stress or shear rate, viscosities or consistency indices, activation energies, frequency factors) of rice-based formulated food products as affected by either malting and/or fermentation. FARO 44 rice cultivar was processed, and different flours obtained were further formulated with processed soybean (*Glycine max*) flour. In each of those mixing ratios, 16% protein (PAG's recommendations) was obtained by a material balance equation. A digital viscometer was used to measure the viscosities of the gruels at levels of 4 concentrations, 4 shear rates and 6 temperatures. Subsequently, the Power law fluids model, Arrhenius kinetic type equation, and linear regression analysis (at levels of 4 concentrations, 4 shear rates and 6 temperatures) were employed to generate the rheological parameters of the gruels. Results showed that viscosity decreased with an increase in temperature within the 30 - 80 °C range studied and shear rate (6 - 60 rpm.) but increased with an increase in concentration (5 - 20%) of gruels. Regardless of temperature or concentration, the consistency indices (1.68 to 714.32 Ns<sup>n</sup>m<sup>-2</sup>) of gruels, and their respective flow behaviour indices (*n*) and activation energy ranged from 0.01 to 0.43 and 5.25 to 36.97 kJ/mol. All formulated products exhibited pseudoplasticity and sensitivity to temperature change. Malting and/or fermentation showed a significant ( $p < 0.05$ ) reduction in viscosities and revealed that it can be used to increase the nutrient density required by infants.

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### 1.0 Introduction

Rheology is the study of how a material deforms or flows over time scale, while viscosity measures the internal resistance of a material to flow in response to the applied force (Figura and Teixeira, 2007; Nielsen, 2010). It is necessary to understand the flow behaviour of the food system undergoing processing and also, its acceptability and taxonomy after processing.

The dependency on fluid flow or deformation behaviours may contribute to undesirable effects in nature and subsequently interfere with human activities. For example, in the case of most agricultural products such as paste, gruels, food powders etc. the viscosity of the food product due to its non-Newtonian behaviours may create hold-up, jamming, heating effects etc. to the processing machine (s). Defects such as caking, clumping, sticking and solidifying of food products during processing or preparation are problems often accompanied by changes in food products' viscosities. These changes may contribute to sieving, filtration, mixing or conveying difficulties as well as functional defects, sensory changes or nutrient reduction in the food etc. and later deprive its consumers of substantial benefits.

Earlier researchers recommended suitable viscosity of gruels between 1000 and 3000 centipoises (1 to 3 Nsm<sup>-2</sup>) for cereal based infant foods (Mosha and Svanberg, 1983; Badau *et al.*, 2016). Conventional complementary foods come with mixing prescriptions that will adequately meet the nutritional demands of an infant. Those made of cereal, if stuck to the recommended mixing ratio (powder to water) may not flow freely like breast milk. Most infants would either reject or find it difficult to accept complementary food that is too thick. At this critical stage, if the mixture is too thick, the mother or care giver is left with the discretion of diluting it to enable the child to accept it. Hence, depriving the child of the required energy per serving because of too much water in the mixture which have been taken. Besides these, majority of the mothers at the domestic level who prefer to produce cereal-based complementary food for their babies had more knowledge of complementing staple starchy diet with rich protein sources. However, many mothers have not been enlightened about other food processing techniques such as malting or fermentation that would increase energy density for their babies. Malting or fermentation is one of those established locally adaptable technologies for bulk reduction of gruels, which can increase nutrient density for a given gruel consistency. Also, malting and fermentation have been used for reducing the pH of gruels, thereby inhibiting spoilage and pathogenic microorganisms in food (Mosha and Svanberg, 1983; Magala *et al.*, 2015; Mantanjevic *et al.*, 2017).

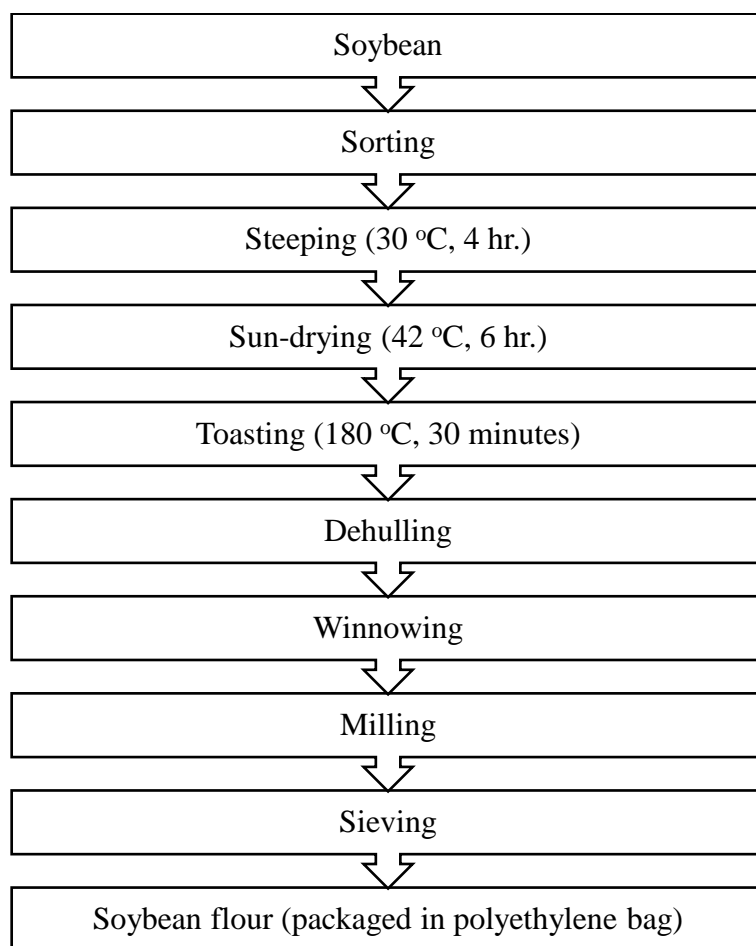
These technologies have been used extensively for improving sensory characteristics of foods, health promoting attributes, reduction of non-digestible carbohydrates, saccharification of starch, phytate degradation, bioactive component concentration, food preservation, production of essential amino acids and vitamins (Bristone *et al.*, 2021; Wu *et al.*, 2022). However, these practices often being neglected in the food industries for the production of conventional infant foods. Probably, due to the time or difficulties accompanying malting or fermentation and the type of profit yield thereafter. But one would not ignore the substantial benefits of formulating an acceptable cereal infant food with resolved dietary bulk reduction.

Nowadays, rice among many other cereal grains or soybean among other legumes are the most receiving global attention for human consumption (Bristone *et al.*, 2021; García-Salcedo *et al.*, 2023). FARO 44 rice among a series of rice varieties released in the African sub-region has unique properties that have satisfied both farmers' and consumers' preferences (Udemezue and Agwu, 2018; Ebenehi and Ahmed, 2019; Idu *et al.*, 2021). However, behaviours of FARO 44 rice variety in food systems especially those of rheological properties have not been studied. More importantly, how malting and/or fermentation would influence the flow behaviour of rice products for its acceptability. Therefore, a combination of malted and/or fermented rice with soybean holds the potential for increasing utilization of the adopted technologies and addressing low-energy density gruels that have implications in infant malnutrition.

## 2. Materials and Methods

### 2.1 Preliminary Handling and Processing

In this study, FARO 44 rice (paddy) was obtained from the National Cereals Research Institute (NCRI), Badeggi, Bida, Niger State, and destoned using a mechanical de-stoner (De-Stoner, Hunan Sunfied Machinery Co., Ltd, Model: TQS 320, China). Also, soybean (*Glycine max*) was procured from Agricultural Seed Store House, Gire Local Government, Adamawa State. The soybean was cleaned to remove contaminants. It was steeped into clean water for four (4) hours to reduce antinutrients. This operation was followed immediately by sun-drying, toasting and dehulling of the soybean as described by Badau *et al.* (2016). The dehulled soybean was processed into flour (Figure 1) (Badau *et al.* 2016), packaged in air-tight polythene bags, and placed inside plastic containers with lids as well as stored on a dry shelf at ambient conditions of average temperature of about 30 °C and humidity 32% (Badau *et al.*, 2016; Bristone *et al.*, 2021). After cleaning the paddy, it was divided into two equal lots. The first lot was malted while the second lot was left un-malted. Paddy was washed twice with clean water. The cleaned paddy rice was steeped inside sufficient clean water to cover the surface of the grains completely. It was kept at 29 ± 2 °C with good air circulation for 24 hours. The steeping process was interrupted after every 6 hours by draining. An "air-rest" period of one hour each for every interruption was provided. The steeped paddy was then drained and wrapped in a wet jute bag to provide about 3 to 5 cm depth. FARO 44 grain sample was germinated for 43 hours at 29 ± 1 °C. The short period of germination was timed and was done to counter technical difficulties during dehulling of malted rice as experienced during pre-trials. After drying of germinated grains at 29 ± 2 °C under constant air circulations for 48 hours, the germinated dried grains were polished by detaching the roots and rootlet (Gasinski *et al.*, 2020; Bristone *et al.*, 2021).

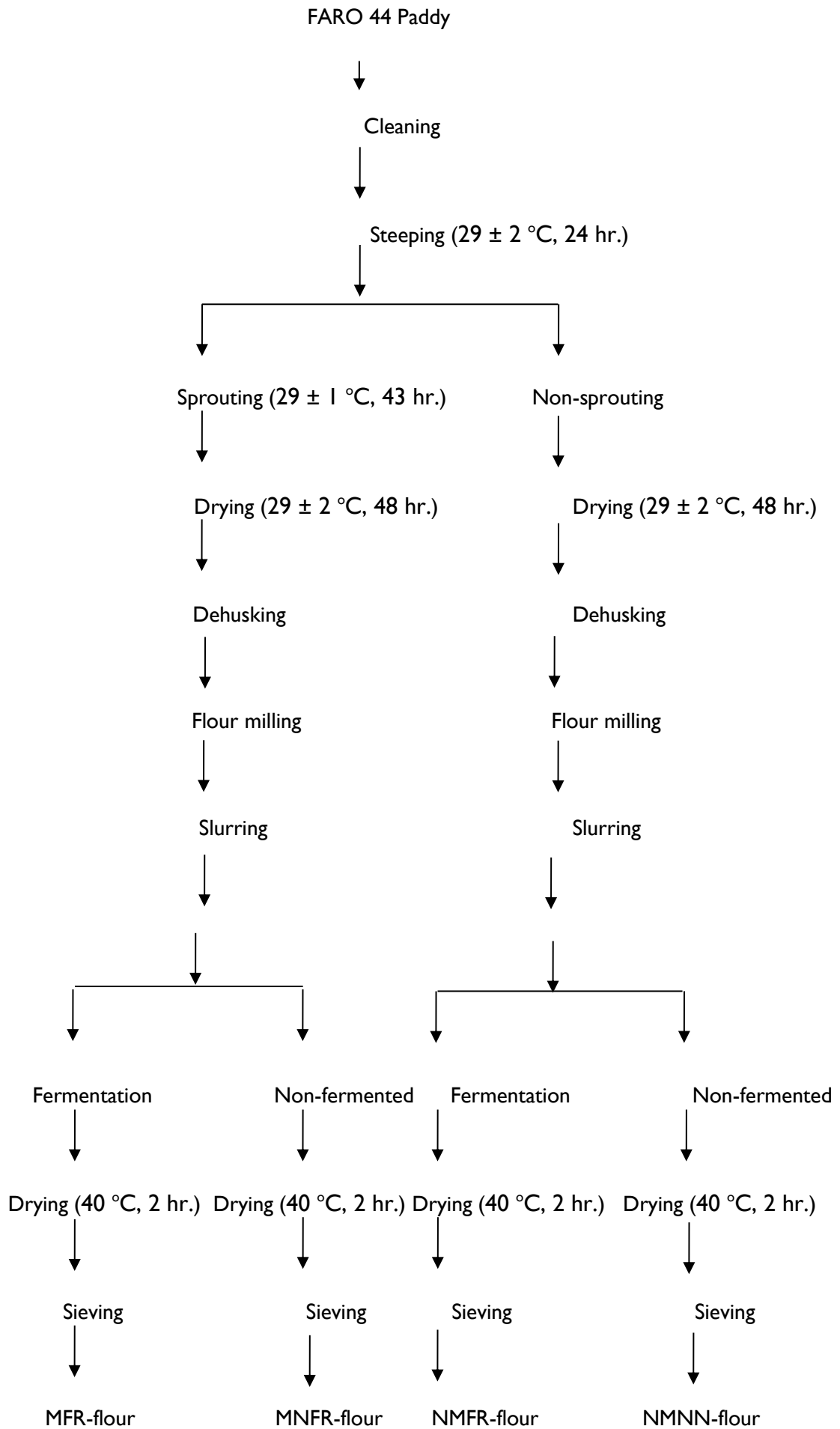


**Figure 1:** Flow chart for the production of soybean flour (Badau *et al.*, 2016).

About 40 kg of cleaned and dried paddy for each lot was de-husked using a Greep rice mill (Model-MBLN-115, China). After de-husking, the grains were finally dried again at 40 °C in an air flow thermostat oven (air flow rate 140, Oven BS, Model OV-160, Gallen Kamp, England) until constant weight were obtained. Then all the rice was milled using a hammer miller and let to pass through a 0.8 mm sieve (Christy Hunt Agricultural Ltd, Foxhills Ind. Est Scunthorpe, Model DE DNI5 8QW, South Humbers, England). Each of the rice flours obtained from malted and non-malted paddy were further divided into two lots. One lot was selected from each of the divisions and were subjected to solid state accelerated natural fermentation (Bristone *et al.*, 2021). The fermented foods were spread on drying trays and also dried to constant weight in an air draft oven for about 2 hours at 40 °C (Figure 2).

## 2.2 Product Formulations

A 2 x 2 completely randomized experimental design was employed for the study. The design comprised malted and non-malted rice, fermented and non-fermented rice, that yield four test samples which were each combined with the processed soybean flour. The product formulations aimed at obtaining 16 g protein of each test product, recommended by the protein advisory group (PAG) (WFP, 2018). The various amounts were obtained by materials balance equation based on the proximate compositions of the food materials. The flours at appropriate ratios were blended in a dry mixer, parked in self-sealing polythene bags and placed in dry and cleaned plastic containers and stored on dry shelves. Four test products comprising non-malted-non-fermented rice + soybean (NMNFRS), malted-non-fermented rice + soybean (MNFERS), non-malted-fermented rice + soybean (NMFERS) and malted-fermented rice + soybean (MFRS).



**Figure 2:** Flow chart for the production of malted and /or fermented rice flours

MFR = Malted-fermented rice, MNFR = Malted-non fermented rice, NMFR = Non malted-fermented rice and NMNNR = Non malted-non fermented rice.

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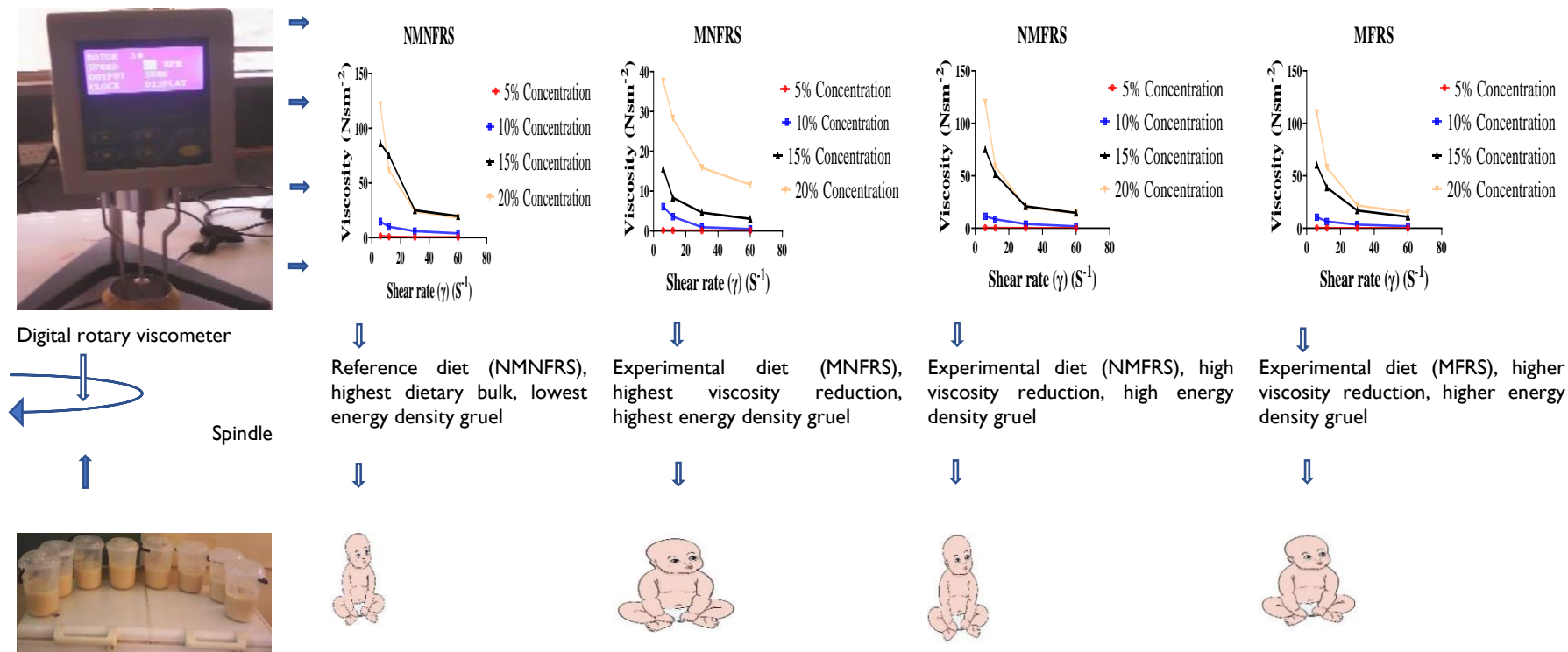
### 2.3 Experimental Set-up and Data Evaluation

Gruels were prepared by mixing the flour of the rice and soybean-based complementary foods with distilled water, inside a coded aluminium can and was heated (cooked) at 95 °C for 7 minutes in a digital thermostatic water bath (Water Bath HH - 420, Model HH - 420. PEC Medical USA). The viscosities of the prepared gruels were measured using a digital rotatory viscometer (Digital Rotary Viscometer, Model: NDJ-55, China) (Figure 3).

A 4 × 4 × 6 (4 concentrations: 5, 10, 15 and 20% w/v; 4 shear rates: speed of 6, 12, 30, and 60 revolutions per minute and 6 temperatures: 30, 40, 50, 60, 70, and 80 °C) were employed for viscosity measurements of each gruel. About six hundred millilitres (600 ml) aluminium tin was used. The tin was used to cover up to the immersion level point on the shaft of the spindles as recommended by the manufacturer. All viscosity measurements were carried out immediately after preparing the gruels. A digital thermostatic water bath was used to maintain temperature stability. However, it was assisted with ice water for rapid cooling of the hot gruel to a desired temperature level (e.g., from 95 to 80 °C).

Data generated were subjected to analysis of variance (One way - ANOVA) using IBM SPSS statistics version 22 and mean values were separated by Duncan's Multiple Range Test (DMRT) at a 5% significant level.

A plot of viscosity versus shear rate and a natural log of viscosity versus a natural log of shear rate were plotted. An Oswald de Waele model (power law fluids model) was used to describe the rheological behaviours of the formulated food products (Sopade and Kasum, 1992a; Mouquet and Treche, 2001; Fraiha *et al.* 2011; Adebowale and Sani, 2011). This mathematical model was selected because most foods fall within the non - Newtonian fluids group and can simply be described and characterized by a two - parameter model of the power law fluids model.



**Figure 3:** Viscosity measurements, concepts and implications in the experimental diets

Data obtained were fitted with the power law model:

$$\mu = k\gamma^{n-1} \quad (1)$$

where  $\mu$  = viscosity ( $\text{Nsm}^{-2}$ ),  $\gamma$  = share rate (rpm),  $n$  = flow behaviour index,  $k$  = consistency index ( $\text{Ns}^n\text{m}^{-2}$ ). Linearization of equation 1 gives:

$$\ln\mu = \ln k + (n - 1) \gamma \quad (2)$$

Temperature dependency of the viscosities were verified using Arrhenius type relationship:

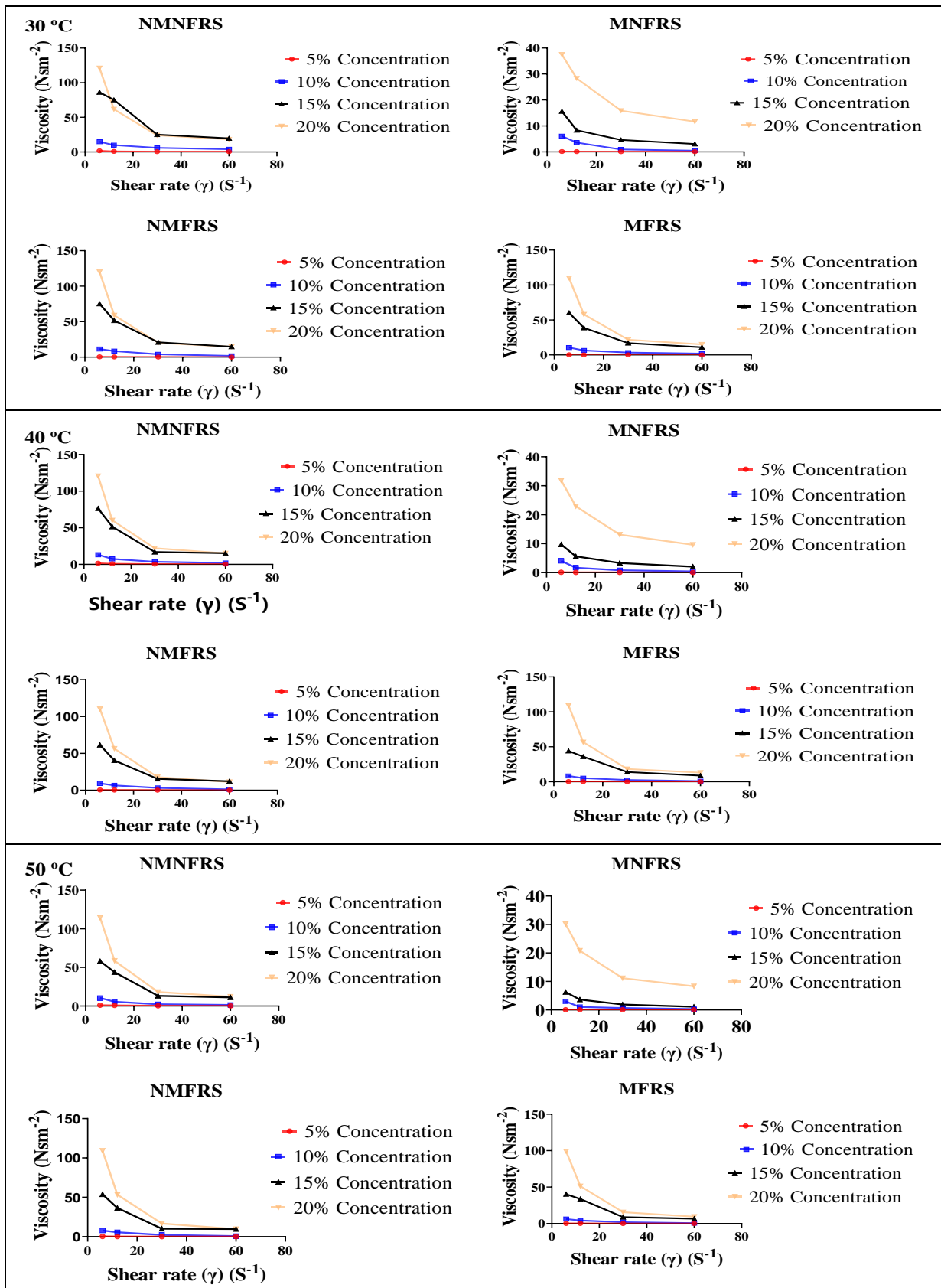
$$\mu = \mu_0 e^{-E_a/RT} \quad (3)$$

where:  $\mu_0$  = frequency factor,  $E_a$  = activation energy (kJ/mol),  $R$  = universal gas constant (0.008314 kJ/mol. K) and  $T$  = absolute temperature ( $^{\circ}\text{K}$ ). Regression coefficient ( $r^2$ ) was used to verify goodness of fit of the power law model and Arrhenius type equation.

### 3. Results and Discussion

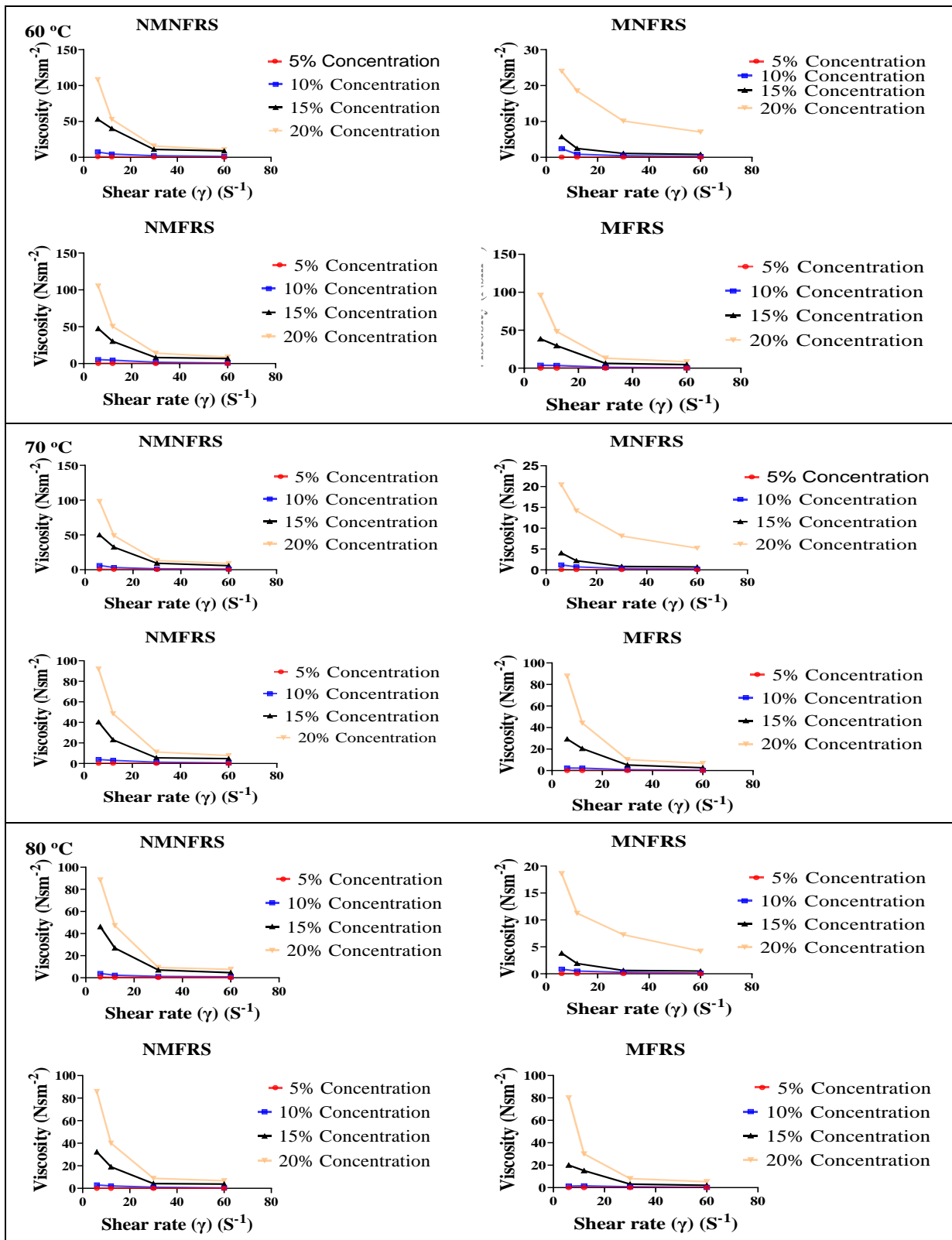
#### 3.1 Influence of Viscosity and Power Law Derivatives

In Figures 4a, 4b (plots of viscosity versus shear rate) and 5a, 5b (plots of log of viscosity versus log of shear rate), the effect of temperature, concentration and shear rate on viscosity of gruels from the formulated products are shown. Their respective viscosity values (Tables I - 4) of the formulated food gruels irrespective of concentrations, temperatures and shear rates varied significantly ( $p < 0.05$ ) and ranged from 0.14 to 121.22  $\text{Nsm}^{-2}$  (NMNFRS), 0.01 to 37.50  $\text{Nsm}^{-2}$  (MNFRS), 0.03 to 120.10  $\text{Nsm}^{-2}$  (NMFRS) and 0.02 to 110.04  $\text{Nsm}^{-2}$  (MFRS). The influence of viscosity reduction in this study is related to enzyme activities. Grain enzymes (such as  $\alpha$ - $\beta$  amylases etc.) are mostly synthesized (generated) in the grain during germination. These enzymes are majorly responsible for the saccharification and dextrinization of starch leading to liquefaction (decrease in viscosity) of gruels. Enzymes have optimum (pH, temperature, etc.) and can be affected by fermentation.

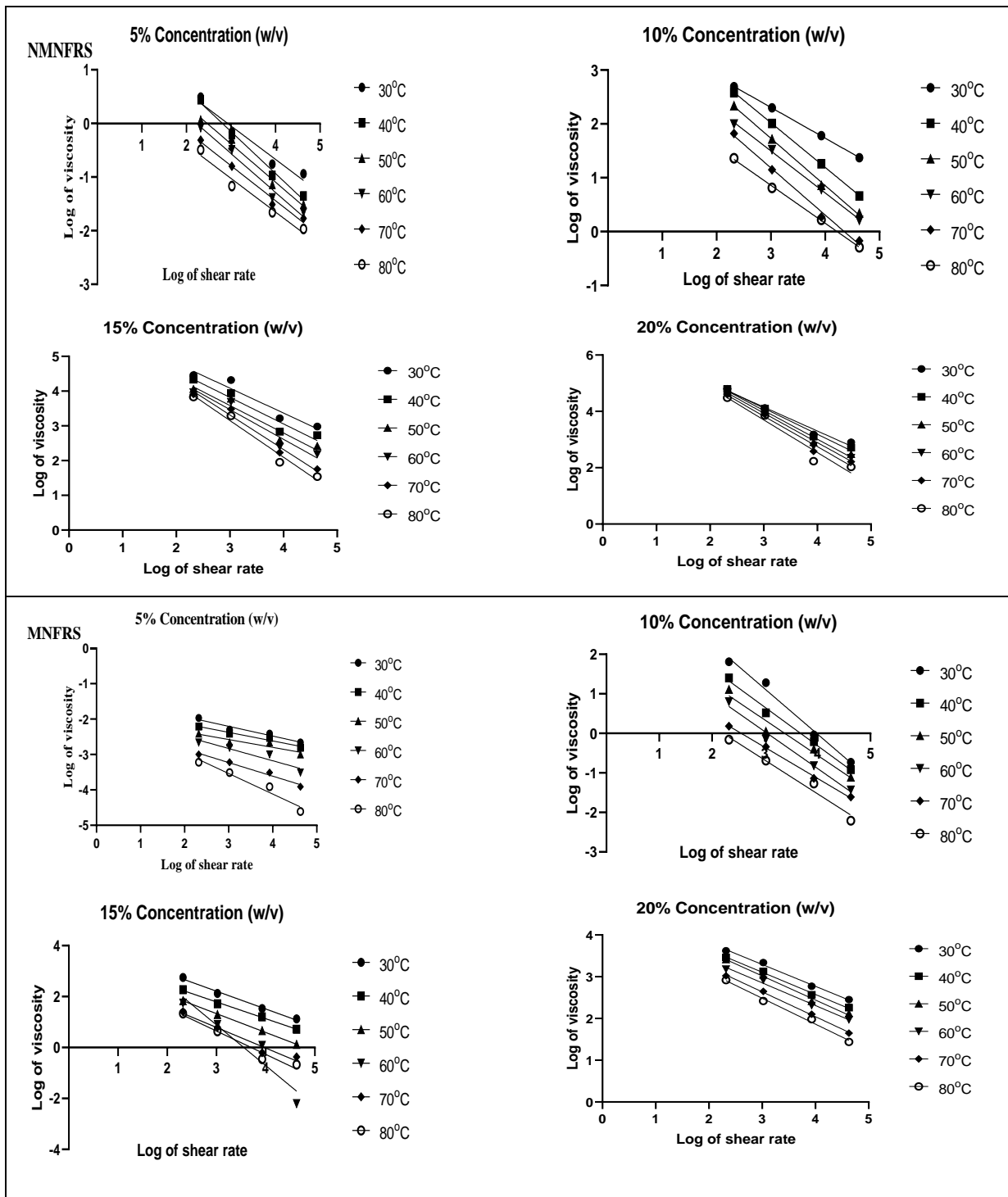


**Figure 4a:** Effect of concentration and shear rate on viscosity of non-malted-non-fermented rice (NMNFR), malted-non-fermented rice (MNFR), non-malted-fermented rice (NMFR) and malted-fermented rice (MFR) at 30, 40 and 50 °C, S: Soybean.

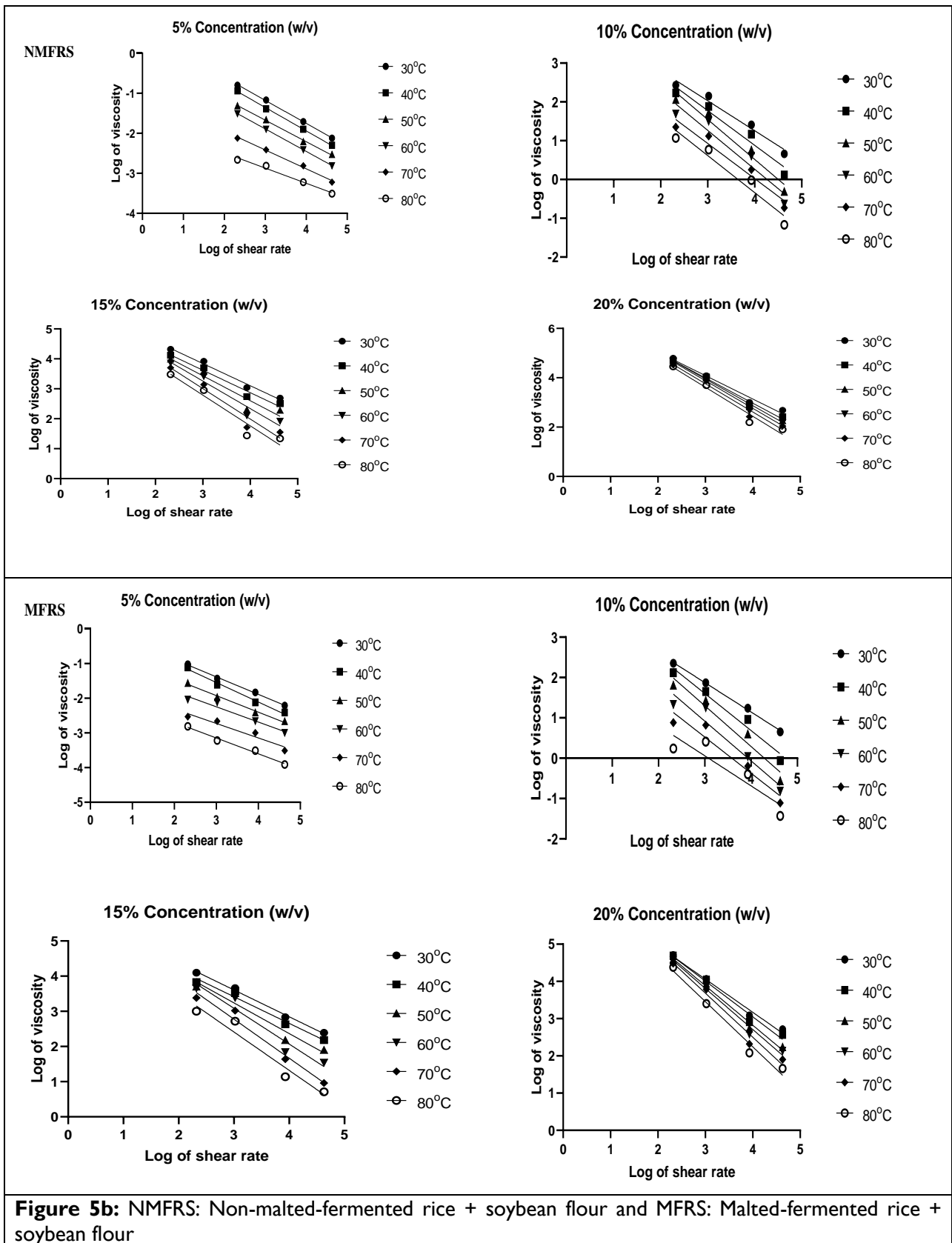




**Figure 4b:** Effect of concentration and shear rate on viscosity of non-malted-non-fermented rice (NMNFR), malted-non-fermented rice (MNFR), non-malted-fermented rice (NMFR) and malted-fermented rice (MFR) at 60, 70 and 80 °C. S: Soybean.



**Figure 5a:** NMNFRS: Non-malted-non-fermented rice + soybean flour and MNFRS: Malted- non-fermented rice + soybean flour



**Figure 5b:** NMFRS: Non-malted-fermented rice + soybean flour and MFRS: Malted-fermented rice + soybean flour

**Table 1:** Viscosity of non-malted-non-fermented rice (NMNFR) plus soybean based complementary food

Gruel concentration (%)	Shear rate (rpm)	Viscosity (Nsm <sup>-2</sup> )					
		Temperature (°C)					
		30	40	50	60	70	80
5	6	1.63 <sup>m</sup>	1.56 <sup>m</sup>	1.06 <sup>m</sup>	0.92 <sup>m</sup>	0.73 <sup>m</sup>	0.61 <sup>m</sup>
	12	0.85 <sup>n</sup>	0.81 <sup>n</sup>	0.75 <sup>n</sup>	0.61 <sup>n</sup>	0.45 <sup>n</sup>	0.31 <sup>n</sup>
	30	0.47 <sup>o</sup>	0.38 <sup>o</sup>	0.32 <sup>o</sup>	0.25 <sup>o</sup>	0.22 <sup>o</sup>	0.19 <sup>o</sup>
	60	0.39 <sup>p</sup>	0.26 <sup>p</sup>	0.22 <sup>p</sup>	0.19 <sup>p</sup>	0.17 <sup>p</sup>	0.14 <sup>p</sup>
10	6	14.74 <sup>i</sup>	13.20 <sup>i</sup>	10.40 <sup>i</sup>	7.36 <sup>i</sup>	6.20 <sup>i</sup>	3.91 <sup>i</sup>
	12	9.96 <sup>j</sup>	7.45 <sup>j</sup>	5.61 <sup>j</sup>	4.59 <sup>j</sup>	3.16 <sup>j</sup>	2.25 <sup>j</sup>
	30	5.92 <sup>k</sup>	3.54 <sup>k</sup>	2.36 <sup>k</sup>	2.18 <sup>k</sup>	1.31 <sup>k</sup>	1.24 <sup>k</sup>
	60	3.93 <sup>l</sup>	1.93 <sup>l</sup>	1.40 <sup>l</sup>	1.23 <sup>l</sup>	0.84 <sup>l</sup>	0.75 <sup>l</sup>
15	6	86.20 <sup>b</sup>	76.30 <sup>b</sup>	58.01 <sup>c</sup>	53.01 <sup>b</sup>	50.06 <sup>b</sup>	46.23 <sup>c</sup>
	12	75.20 <sup>c</sup>	51.40 <sup>d</sup>	43.80 <sup>d</sup>	40.11 <sup>d</sup>	32.40 <sup>d</sup>	26.89 <sup>d</sup>
	30	25.01 <sup>e</sup>	16.97 <sup>f</sup>	13.24 <sup>f</sup>	11.01 <sup>f</sup>	9.32 <sup>f</sup>	7.04 <sup>g</sup>
	60	19.66 <sup>g</sup>	15.26 <sup>g</sup>	11.22 <sup>h</sup>	8.92 <sup>h</sup>	5.76 <sup>h</sup>	4.65 <sup>h</sup>
20	6	121.22 <sup>a</sup>	120.60 <sup>a</sup>	114.33 <sup>a</sup>	108.21 <sup>a</sup>	98.13 <sup>a</sup>	88.53 <sup>a</sup>
	12	61.70 <sup>d</sup>	60.20 <sup>c</sup>	58.50 <sup>b</sup>	52.90 <sup>c</sup>	49.00 <sup>c</sup>	47.20 <sup>b</sup>
	30	24.00 <sup>f</sup>	22.10 <sup>e</sup>	18.20 <sup>e</sup>	15.80 <sup>e</sup>	13.20 <sup>e</sup>	9.30 <sup>e</sup>
	60	18.20 <sup>h</sup>	15.10 <sup>h</sup>	12.00 <sup>g</sup>	10.60 <sup>g</sup>	9.10 <sup>g</sup>	7.60 <sup>f</sup>

Each result is mean of triplicate determinations. Values with common superscripts along each column are not significantly ( $p > 0.05$ ) different.

**Table 2:** Viscosity of malted-non fermented rice (MNFR) plus soybean based complementary food

Gruel concentration (%)	Shear rate (rpm)	Viscosity (Nsm <sup>-2</sup> )					
		Temperature (°C)					
		30	40	50	60	70	80
5	6	0.14 <sup>m</sup>	0.11 <sup>m</sup>	0.09 <sup>m</sup>	0.07 <sup>m</sup>	0.05 <sup>m</sup>	0.04 <sup>m</sup>
	12	0.10 <sup>n</sup>	0.09 <sup>n</sup>	0.07 <sup>n</sup>	0.06 <sup>n</sup>	0.04 <sup>n</sup>	0.03 <sup>n</sup>
	30	0.09 <sup>o</sup>	0.08 <sup>o</sup>	0.07 <sup>n</sup>	0.05 <sup>o</sup>	0.03 <sup>o</sup>	0.02 <sup>o</sup>
	60	0.07 <sup>p</sup>	0.06 <sup>p</sup>	0.05 <sup>p</sup>	0.03 <sup>p</sup>	0.02 <sup>p</sup>	0.01 <sup>p</sup>
10	6	6.08 <sup>g</sup>	4.06 <sup>g</sup>	3.02 <sup>g</sup>	2.42 <sup>g</sup>	1.20 <sup>g</sup>	0.85 <sup>g</sup>
	12	3.59 <sup>i</sup>	1.69 <sup>j</sup>	1.05 <sup>i</sup>	0.86 <sup>i</sup>	0.71 <sup>i</sup>	0.50 <sup>i</sup>
	30	0.96 <sup>k</sup>	0.81 <sup>k</sup>	0.67 <sup>k</sup>	0.44 <sup>k</sup>	0.32 <sup>k</sup>	0.28 <sup>k</sup>
	60	0.48 <sup>l</sup>	0.40 <sup>l</sup>	0.33 <sup>l</sup>	0.24 <sup>l</sup>	0.20 <sup>l</sup>	0.11 <sup>l</sup>
15	6	15.60 <sup>d</sup>	9.70 <sup>d</sup>	6.28 <sup>e</sup>	5.70 <sup>e</sup>	4.05 <sup>e</sup>	3.82 <sup>e</sup>
	12	8.35 <sup>f</sup>	5.60 <sup>f</sup>	3.66 <sup>f</sup>	2.46 <sup>f</sup>	2.20 <sup>f</sup>	1.90 <sup>f</sup>
	30	4.60 <sup>h</sup>	3.31 <sup>h</sup>	1.93 <sup>h</sup>	1.08 <sup>h</sup>	0.82 <sup>h</sup>	0.63 <sup>h</sup>
	60	3.06 <sup>i</sup>	2.05 <sup>i</sup>	1.13 <sup>i</sup>	0.82 <sup>j</sup>	0.69 <sup>j</sup>	0.51 <sup>i</sup>
20	6	37.50 <sup>a</sup>	31.80 <sup>a</sup>	30.16 <sup>a</sup>	24.01 <sup>a</sup>	20.42 <sup>a</sup>	18.60 <sup>a</sup>
	12	28.30 <sup>b</sup>	22.90 <sup>b</sup>	20.81 <sup>b</sup>	18.50 <sup>b</sup>	14.20 <sup>b</sup>	11.25 <sup>b</sup>
	30	15.88 <sup>c</sup>	13.11 <sup>c</sup>	11.16 <sup>c</sup>	10.12 <sup>c</sup>	8.14 <sup>c</sup>	7.25 <sup>c</sup>
	60	11.64 <sup>e</sup>	9.63 <sup>e</sup>	8.31 <sup>d</sup>	7.07 <sup>d</sup>	5.22 <sup>d</sup>	4.21 <sup>d</sup>

Each result is mean of triplicate determinations. Values with common superscripts along each column are not significantly ( $p > 0.05$ ) different.

**Table 3:** Viscosity of non-malted-fermented rice (NMFR) plus soybean based complementary food

Gruel concentration (%)	Shear rate (rpm)	Viscosity (Nsm <sup>-2</sup> )					
		Temperature (°C)					
		30	40	50	60	70	80
5	6	0.45 <sup>m</sup>	0.39 <sup>m</sup>	0.27 <sup>m</sup>	0.22 <sup>m</sup>	0.12 <sup>m</sup>	0.07 <sup>m</sup>
	12	0.31 <sup>n</sup>	0.25 <sup>n</sup>	0.19 <sup>n</sup>	0.15 <sup>n</sup>	0.09 <sup>n</sup>	0.06 <sup>n</sup>
	30	0.18 <sup>o</sup>	0.15 <sup>o</sup>	0.11 <sup>o</sup>	0.09 <sup>o</sup>	0.06 <sup>o</sup>	0.04 <sup>o</sup>
	60	0.12 <sup>p</sup>	0.10 <sup>p</sup>	0.08 <sup>p</sup>	0.06 <sup>p</sup>	0.04 <sup>p</sup>	0.03 <sup>p</sup>
10	6	11.38 <sup>i</sup>	9.31 <sup>i</sup>	7.82 <sup>i</sup>	5.41 <sup>i</sup>	3.84 <sup>i</sup>	2.92 <sup>i</sup>
	12	8.56 <sup>j</sup>	6.54 <sup>j</sup>	5.56 <sup>j</sup>	4.50 <sup>j</sup>	3.05 <sup>j</sup>	2.16 <sup>j</sup>
	30	4.11 <sup>k</sup>	3.21 <sup>k</sup>	2.13 <sup>k</sup>	1.82 <sup>k</sup>	1.28 <sup>k</sup>	0.98 <sup>k</sup>
	60	1.94 <sup>l</sup>	1.13 <sup>l</sup>	0.73 <sup>l</sup>	0.53 <sup>l</sup>	0.48 <sup>l</sup>	0.31 <sup>l</sup>
15	6	75.20 <sup>b</sup>	61.42 <sup>b</sup>	53.80 <sup>b</sup>	47.60 <sup>c</sup>	40.40 <sup>c</sup>	32.30 <sup>c</sup>
	12	51.51 <sup>d</sup>	40.41 <sup>d</sup>	36.41 <sup>d</sup>	30.22 <sup>d</sup>	23.02 <sup>d</sup>	19.03 <sup>d</sup>
	30	20.92 <sup>e</sup>	15.43 <sup>f</sup>	10.01 <sup>f</sup>	8.13 <sup>g</sup>	5.52 <sup>g</sup>	4.22 <sup>g</sup>
	60	14.72 <sup>g</sup>	12.21 <sup>g</sup>	9.73 <sup>g</sup>	6.82 <sup>h</sup>	4.71 <sup>h</sup>	3.82 <sup>h</sup>
20	6	120.10 <sup>a</sup>	110.21 <sup>a</sup>	109.00 <sup>a</sup>	105.20 <sup>a</sup>	92.00 <sup>a</sup>	85.80 <sup>a</sup>
	12	59.01 <sup>c</sup>	56.40 <sup>c</sup>	53.30 <sup>c</sup>	50.40 <sup>b</sup>	48.50 <sup>b</sup>	40.00 <sup>b</sup>
	30	20.00 <sup>f</sup>	17.80 <sup>e</sup>	16.70 <sup>e</sup>	14.20 <sup>e</sup>	11.20 <sup>e</sup>	8.90 <sup>e</sup>
	60	14.60 <sup>h</sup>	11.20 <sup>h</sup>	9.60 <sup>h</sup>	8.80 <sup>f</sup>	7.70 <sup>f</sup>	6.70 <sup>f</sup>

Each result is mean of triplicate determinations. Values with common superscripts along each column are not significantly ( $p > 0.05$ ) different.

**Table 4:** Viscosity of malted-fermented rice (MFR) plus soybean based complementary food

Gruel concentration (%)	Shear rate (rpm)	Viscosity (Nsm <sup>-2</sup> )					
		Temperature (°C)					
		30	40	50	60	70	80
5	6	0.36 <sup>m</sup>	0.33 <sup>m</sup>	0.21 <sup>m</sup>	0.13 <sup>m</sup>	0.08 <sup>m</sup>	0.06 <sup>m</sup>
	12	0.24 <sup>n</sup>	0.20 <sup>n</sup>	0.14 <sup>n</sup>	0.12 <sup>n</sup>	0.07 <sup>n</sup>	0.04 <sup>n</sup>
	30	0.16 <sup>o</sup>	0.12 <sup>o</sup>	0.09 <sup>o</sup>	0.07 <sup>o</sup>	0.05 <sup>o</sup>	0.03 <sup>o</sup>
	60	0.11 <sup>p</sup>	0.09 <sup>p</sup>	0.09 <sup>p</sup>	0.05 <sup>p</sup>	0.03 <sup>p</sup>	0.02 <sup>p</sup>
10	6	10.52 <sup>i</sup>	8.36 <sup>i</sup>	6.14 <sup>i</sup>	3.78 <sup>i</sup>	2.41 <sup>i</sup>	1.30 <sup>i</sup>
	12	6.47 <sup>j</sup>	5.21 <sup>j</sup>	4.19 <sup>j</sup>	3.50 <sup>j</sup>	2.26 <sup>j</sup>	1.51 <sup>j</sup>
	30	3.47 <sup>k</sup>	2.62 <sup>k</sup>	1.83 <sup>k</sup>	1.04 <sup>k</sup>	0.82 <sup>k</sup>	0.67 <sup>k</sup>
	60	1.92 <sup>l</sup>	0.94 <sup>l</sup>	0.57 <sup>l</sup>	0.44 <sup>l</sup>	0.33 <sup>l</sup>	0.24 <sup>l</sup>
15	6	60.36 <sup>b</sup>	46.10 <sup>c</sup>	40.30 <sup>c</sup>	38.60 <sup>c</sup>	29.30 <sup>c</sup>	20.01 <sup>c</sup>
	12	38.85 <sup>d</sup>	35.90 <sup>d</sup>	33.72 <sup>d</sup>	29.50 <sup>d</sup>	20.43 <sup>d</sup>	15.15 <sup>d</sup>
	30	16.99 <sup>f</sup>	13.89 <sup>f</sup>	8.81 <sup>g</sup>	6.29 <sup>g</sup>	5.18 <sup>g</sup>	3.13 <sup>g</sup>
	60	10.93 <sup>h</sup>	8.83 <sup>h</sup>	6.66 <sup>h</sup>	4.65 <sup>h</sup>	2.61 <sup>h</sup>	2.04 <sup>h</sup>
20	6	110.04 <sup>a</sup>	109.03 <sup>a</sup>	99.03 <sup>a</sup>	95.90 <sup>a</sup>	87.80 <sup>a</sup>	80.08 <sup>a</sup>
	12	58.10 <sup>c</sup>	56.70 <sup>b</sup>	51.37 <sup>b</sup>	48.35 <sup>b</sup>	44.21 <sup>b</sup>	30.01 <sup>b</sup>
	30	21.83 <sup>e</sup>	18.36 <sup>e</sup>	15.51 <sup>e</sup>	13.22 <sup>e</sup>	10.18 <sup>e</sup>	8.02 <sup>e</sup>
	60	15.02 <sup>g</sup>	13.10 <sup>g</sup>	9.41 <sup>f</sup>	8.44 <sup>f</sup>	6.71 <sup>f</sup>	5.28 <sup>f</sup>

Each result is mean of triplicate determinations. Values with common superscripts along each column are not significantly ( $p > 0.05$ ) different.

Also, fermentation can cause the breakdown of starch by endogenous enzymes of the grain or available enzymes of microorganisms produced during fermentation, which may in turn not be adequate or specific for liquefaction in this study. Taken into account viscosity reduction in this study is an indicator of enzyme activities. It is obvious  $\alpha$ - $\beta$  amylases were majorly synthesized or produced during germination since the viscosity of NMNFRS did not change. But when the rice was malted which yielded MNFRS, its viscosity decreased drastically as compared to the viscosity of NMNFRS. Similarly, when the rice was malted and fermented to yield MFRS, its viscosity decreased slightly as compared to the viscosity of NMNFRS. This mean

enzymatic hydrolysis responsible for viscosity reduction in the malted rice was inhibited by fermentation. This shows that enzyme activities responsible for the reduction of viscosity in this study were mostly generated (synthesized) during malting than fermentation. However, a slight decrease in the viscosity of NMFRS is evident through the fermentation of the non-malted-non fermented rice flour. Probably because of the activities of enzymes. If it was so, MFRS could have benefitted and doubled the activities of enzymes by the malting and fermentation. These have justified the activities of enzymes derived from the malted rice flour which yielded MFRS. But was majorly hindered by the effect of fermentation. Another plausible reason which may not directly link to enzyme activities, is the average particle dispersion per unit volume in the gruels or generally the geometric properties of particles in the gruels which tend to increase or decrease the velocity gradient of the liquids containing the flour particles. Hence, increases or decrease the viscosities of the gruels. Therefore, fermentation has contributed less viscosity reduction as can be seen in the non-malted flour that was fermented to yield NMFRS as compared to the NMNFRS.

Also, it was generally observed that the viscosities of gruels decreased with an increase in temperature within the 30 to 80 °C range studied and shear rate (6 - 60 rpm.) but increased with an increase in concentration (5 - 20%) of gruels. Malting and fermentation resulted in a significant ( $p < 0.05$ ) decrease in viscosities at all shear rates and temperatures with the magnitude of viscosities being highest for the non-malted-non-fermented sample and lowest for malted-non-fermented sample (Figures 4a and 4b). The linear plots of the log of viscosity versus the log of shear rate also revealed or depicted the effects of temperature, concentration and shear rate on the gruels of formulated foods (Figures 5a and 5b) as in the case of viscosity versus shear rate. The plots of viscosity versus shear rate and those of linear plots of log of viscosity versus log of shear rate were better correlated and followed similar trends in terms of the effect of temperature, concentration or shear rate. Viscosity literatures of different food gruels (Sopade and Kassum, 1992a; Sopade and Kassum, 1992b; Mouquet and Treche, 2001; Badau *et al.*, 2006; Taga and Non, 2017) also reported similar trends. However, with some differences of viscosity derivatives. Earlier reports from molecular thermodynamics, 'temperature has a direct effect on molecular motion. As temperature increases, molecules move at a faster rate with great velocity. At low temperatures, molecules come closer together to cause an increase in viscosity. At high temperatures, molecules move far apart from each other causing decrease in viscosity'. However, 'if no other reactions or transformations' such as starch gelatinization, saccharification etc. are involved (Figura and Teixeira, 2007). In a similar vein, 'cohesive forces between the molecules decrease and flow becomes free as temperature increases. Hence, decrease in the viscosity of fluids' (Sahin and Sumnu, 2006). For the shear rates, 'shearing increases or causes friction and entangle long-chain molecules to straighten out and become aligned with the flow. Hence, causing a viscosity decrease' (Figura and Teixeira, 2007). An increase in concentration also increases the binding forces and gather together the molecules into a compact mass to oppose the flow or deformation. Therefore, friction or resistance to flow of the material increases. 'It is based on this idea that solids oppose deformation or flow much more compared to liquids or gases' (Sahin and Sumnu, 2006; Figura and Teixeira, 2007). These factors that contribute to binding forces of the molecules may not be the same with the energy barrier per mole which enables motion. Regardless of shear rate and since a temperature above 40 °C may not be appropriate for feeding of an infant, the appropriate viscosity recommended for infant feeding (Mosha and Svanberg, 1983) would likely be within 15 to 20% concentration for malted-non-fermented rice + soybean and 10 to 15% concentration for the other products. It becomes obvious according to this study, malting alone had more severe effect on the viscosity (much bulk reduction effect) and this signify increase of nutrient density in the food product. Previous studies have shown the viscosity reduction with the addition of 5% power flour in gruels (Mosha and Svanberg, 1983; Badau *et al.*, 2006; Badau *et al.*, 2016; Bristone *et al.*, 2019). But in that case, may not be much if compare with whole malt flour or as in the case of malted-non-fermented rice + soybean.

### 3.2 Consistency and Flow Behaviour Indices of the Formulated Food Products

Consistency and flow behaviour indices of NMNFRS and MNFRS are shown in Table 5a. For NMNFRS consistency indices ( $k$ ) of 5, 10, 15 and 20% concentration of gruels ranged from: 1.68 to 4.46  $\text{Ns}^n\text{m}^{-2}$ , 13.59 to 58.90  $\text{Ns}^n\text{m}^{-2}$ , 221.20 to 350.02  $\text{Ns}^n\text{m}^{-2}$ , 521.51 to 714.32  $\text{Ns}^n\text{m}^{-2}$ , respectively. Also, their respective flow behaviour indices ( $n$ ) are: 0.22 to 0.38, 0.12 to 0.43, 0.01 to 0.28 and 0.02 to 0.16. Regardless of temperature or concentration, their consistency indices ranged from 1.68 to 714.32  $\text{Ns}^n\text{m}^{-2}$ . The accuracy or adequacy and fitness of the fitted model employed was tested by its regression coefficient ( $r^2$ ). The  $r^2$  values entails the satisfaction of the model. In this study, the goodness of the model fit has predicted the rheological parameters of the formulated products accurately, with the  $r^2$  values close to 1 or 1 ( $0.93 \geq x \leq 1$ ) which justified the model parameters appropriately. The power law fluids model was observed to fit the experimental data appropriately at 10% concentration with all the correlation coefficients ( $r^2$ )  $\geq 0.99$  as compared to 5, 15 and

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20% concentrations ( $r^2$ : 0.93 to 0.99). At the same time, at temperatures of 30, 40 and 80 °C, the coefficient of determination was observed to correlate well as compared to other remaining temperatures.

**Table 5a:** Power law derivatives for flow of the formulated food products

Gruel concentration (%)	Parameters	Temperature (°C)					
		30	40	50	60	70	80
		NMNFRS					
5	$r^2$	0.96	0.99	0.99	0.98	0.98	0.97
	n	0.38	0.22	0.28	0.27	0.35	0.37
	k	4.46	5.98	4.01	3.41	2.28	1.68
10	$r^2$	1.00	1.00	0.99	1.00	0.99	1.00
	n	0.43	0.17	0.12	0.22	0.12	0.29
	k	41.31	58.9	49.81	30.80	28.79	13.59
15	$r^2$	0.93	0.94	0.94	0.94	0.98	0.98
	n	0.28	0.23	0.21	0.14	0.03	0.01
	k	350.02	304.97	256.84	269.47	222.67	221.20
20	$r^2$	0.98	0.99	0.99	0.98	0.98	0.95
	n	0.15	0.07	0.02	0.05	0.04	0.16
	k	521.51	606.55	698.27	690.50	676.22	714.32
		MNFRS					
5	$r^2$	0.95	0.96	0.87	0.90	0.98	0.95
	n	0.73	0.76	0.78	0.65	0.62	0.42
	k	0.25	0.19	0.15	0.17	0.13	0.17
10	$r^2$	0.99	0.99	0.96	0.98	1.00	0.97
	n	0.15	0.02	0.10	0.04	0.21	0.15
	k	96.06	36.34	20.78	19.53	7.49	6.59
15	$r^2$	0.99	1.00	1.00	0.97	0.96	0.96
	n	0.30	0.34	0.26	0.15	0.19	0.08
	k	74.07	43.08	34.74	35.77	24.98	29.78
20	$r^2$	0.99	1.00	0.99	0.99	1.00	0.99
	n	0.48	0.47	0.42	0.46	0.41	0.38
	k	129.15	110.50	115.35	88.59	83.18	76.94

NMNFRS: Non-malted-non-fermented rice + soybean flour, MNFRS: Malted-non-fermented rice + soybean flour,  $r^2$ : Correlation coefficient, n: Flow behaviour index and k: Consistency index

The results of all flow behaviour indices (n) were observed to be less than 1. Much less power law indices (average 0.08) were observed at 20% concentration, especially at temperatures of 40, 50, 60 and 70 °C. And as the temperature is increasing, the consistency indices (k) of the gruels decreased. But in the case of the concentration of gruels, the consistency indices generally increased with increasing percentage concentration of solids. In the power law fluids model, k is the consistency index known as apparent viscosity, in contrast to absolute viscosity, but which is also sensitive to temperature changes as absolute viscosity. As the temperature of the gruels increases, the limited free spaces or volumes between the food molecules become more, and this eases the moving molecules, so viscosity decreases with increasing temperatures. However, the ease with which this mobility occurs may be triggered by the velocity gradient. Equally, lowering the density as the temperature increases would cause viscosity reduction. A typical example of a life situation with this viscosity

phenomenon is in an overcrowded area. As the temperature of the overcrowded place increases, people give ways to decongest, creating free spaces (volume) between individuals which would allow or ease movement and at the same time lowering of population density. But as the temperature of the overcrowded area is decreasing, people come together comfortably in mass, and this would restrict movement because of the limited spaces. In the case of consistency indices increasing with increasing concentration, this has to do with the reduction of free spaces or volume between the molecules as particles of food keep filling those free spaces and so consistency indices decrease with increasing concentration. Also, as particles keep filling the free spaces of less concentrated food or liquid, physical or chemical processes such as contraction, dispersion, and aggregation would result between molecules and decrease free volume, and so much more particles in liquid would increase resistance (viscosity) to flow. The geometric nature of these particles may also favour the resistance of these gruels to flow, because movement around each particle may be disturbed or hindered because of the increase (hinder flow) in velocity gradient.

For MNFRS (i.e., Table 5a), consistency indices ( $k$ ) of gruel ranged from 0.13 to 0.25  $\text{Ns}^n\text{m}^{-2}$  (5% concentration), 6.59 to 96.06  $\text{Ns}^n\text{m}^{-2}$  (10% concentration), 24.98 to 74.07  $\text{Ns}^n\text{m}^{-2}$  (15% concentration) and ranged from 76.94 to 129.15  $\text{Ns}^n\text{m}^{-2}$  (20% concentration). Their corresponding power law index ( $n$ ) also ranged from: 0.42 to 0.78, 0.02 to 0.21, 0.08 to 0.34 and 0.38 to 0.41. The power law flow index ( $n$ ) describes the Newtonian or non-Newtonian behaviour. As the flow index ( $n$ ) of the power law fluids model obtained from the linear derivatives tends toward zero, the more the product exhibits pseudoplasticity; and as it tends toward 1 or greater than 1, the more the product exhibits Newtonian or dilatant behaviour, respectively. At the level of 5% concentration, the gruel tends to be pure (low level of particles) than the other concentrations, mimicking the characteristics of Newtonian liquids ( $n = 1$ ). Concentration, temperature and consistency index relationships followed a similar trend (but  $r^2$ : 0.86 to 1.00) as in the case of NMNFRS. Except in terms of the magnitude of consistency indices as compared to the other formulations, which are mostly lower.

For NMFRS and MFRS consistency indices are shown in Table 5b. For NMFRS consistency index ( $k$ ) ranged from: 0.18 to 1.73  $\text{Ns}^n\text{m}^{-2}$ , 32.62 to 103.13  $\text{Ns}^n\text{m}^{-2}$ , 352.13 to 431.38  $\text{Ns}^n\text{m}^{-2}$  and 1031.74 to 1399.68  $\text{Ns}^n\text{m}^{-2}$  for 5, 10, 15 and 20% concentration, respectively. Their corresponding power law index ( $n$ ) also ranged from: 0.42 to 0.62, 0.00 to 0.23, 0.02 to 0.26 and 0.02 to 0.18. Concentration, temperatures and consistency index relationships followed a similar trend as described earlier. The goodness of fit (0.98 to 1.00) of the model at a 5% level of concentration was much better compared to other levels of concentrations in this category ( $r^2$ : 0.91 to 0.99). At concentration and temperature levels of 5% and 60 °C respectively, the  $r^2$  value was up to 1.00 (perfectly fitted). The power law index was observed much less also of the 10, 15 and 20% levels of concentrations at some specific temperature, mostly towards 80 °C and the beginning of 30 °C for 10, 15 and 20% respectively. In this study, the consistency indices were observed mostly higher compared to NMNFRS or MNFRS.

For MFRS (Table 5b) consistency indices ( $k$ ) ranged from: 0.17 to 1.15  $\text{Ns}^n\text{m}^{-2}$ , 10.24 to 78.26  $\text{Ns}^n\text{m}^{-2}$ , 294.42 to 464.05  $\text{Ns}^n\text{m}^{-2}$ , 838.82 to 1388.53  $\text{Ns}^n\text{m}^{-2}$ , for 5, 10, 15, and 20% concentrations, respectively. Their corresponding flow behaviour indices ( $n$ ) ranged from: 0.44 to 0.58, 0.01 to 0.27, 0.20 to 0.24 and 0.04 to 0.21. Similar trend in MFRS (Table 1b) was observed as in the case of NMNFRS (Table 5a). However, the goodness of fit of the model ( $r^2$ : 0.93 to 1.00) correlates much better at 20% concentration, because all the  $r^2$  values were observed  $\geq 0.98$  at that point. But a much better correlation was observed at 10 and 15% concentration and 30 °C. This entails the power law fluids model fits the experimental rheological data accurately at those points than the other values of this study and it was revealed by the  $r^2$  values of the linear correlation. Flow behaviour index was much less at the levels of 10 and 20% concentrations and each with an average of 0.12. A study by Mouquet and Treche (2001) exhibited pseudoplastic behaviour ( $n < 1$ ) similar to this study. Their viscosity study of gruels for complementary food revealed a consistency index of 0.042 to 11.41  $\text{Ns}^n\text{m}^{-2}$  (power law index 0.54 to 0.69) at a temperature of 45 °C, concentration of 7.82% solids, shear rates from 8 to 800  $\text{s}^{-1}$  and also at 62.5 rpm. But correlate much better with this study of the 5% concentration of all formulations in terms of consistency index and also at 10% concentration of the malted-non-fermented rice + soybean. However, their report was observed to be slightly higher compared to this study. Another study by Sopade and Kassum (1992a), reported a contrary consistency index of traditional complementary food (*Akamu*) from 1.55 to 9.56  $\text{Ns}^n\text{m}^{-2}$ , except for the non-malted-non-fermented rice + soybean at 5% concentration in this study. However, their power law indices (0.33 to 0.37) are generally slightly in-between power law indices of the current study. Rheological characterization of a beverage and a complementary food (*Kunu zaki* and *Kunun gyada*) by Sopade and Kassum (1992b) exhibited pseudoplastic or dilatant behaviours. Also, a contrary consistency index of 0.0122 to 0.0243  $\text{Nsm}^{-2}$  (power law index 0.877 to 1.169). However, the consistency index of *Kunun gyada* 0.52 to 1.67  $\text{Nsm}^{-2}$  (power law index 0.28 to 0.39) in their reports were

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within the range of 5% concentrations of the malted-non-fermented rice + soybean and non-malted-fermented rice + soybean. Despite vast data or power law indices generated in this current study and ones reported (0.3184 to 0.5315) by Badau *et al.* (2006), most did not correspond. The use of lower (0.5, 1.0, 2.5 rpm) and higher (100 rpm) shear rates in their study or higher temperatures (60, 70, 80 °C) employed in this study are the major contributing factors for such disparity since their  $r^2$  values (-0.9993 to -0.9524) match the  $r^2$  values (0.83 to 1.00) of this study. Nevertheless, their finding exhibited pseudoplastic behaviour ( $0 < n < 1$ ) and consistency indices of 2.749 to 4.4615  $Ns^{n-1}$  (power law index from 0.3184 to 0.5315) as affected by the addition of malt in formulations, which agreed with the 5% concentration of the non-malted-non-fermented rice + soybean. Sorghum products exhibited pseudoplastic or dilatancy as reported by Taga and Non (2017) but their consistency index (0.158 to 34.484  $Nsm^{-2}$ ) corresponded with the 5 and 10% concentrations of the formulated products.

**Table 5b:** Power law derivatives for flow of the formulated food products

Gruel concentration (%)	Parameters	Temperature (°C)					
		30	40	50	60	70	80
		NMFRS					
5	$r^2$	1.00	1.00	1.00	1.00	0.99	0.98
	n	0.43	0.42	0.46	0.44	0.53	0.62
	k	1.73	1.49	0.94	0.82	0.37	0.18
10	$r^2$	0.97	0.95	0.96	0.92	0.95	0.94
	n	0.23	0.10	0.03	0.00	0.09	0.04
	k	77.25	86.66	103.13	71.74	38.55	32.62
15	$r^2$	0.99	0.97	0.91	0.95	0.95	0.93
	n	0.26	0.25	0.17	0.08	0.02	0.03
	k	431.38	353.19	375.78	411.99	427.52	352.13
20	$r^2$	0.98	0.99	0.99	0.99	0.97	0.96
	n	0.05	0.02	0.08	0.12	0.15	0.18
	k	1031.74	1172.62	1335.42	1399.68	1331.42	1271.56
		MFRS					
5	$r^2$	0.96	0.99	0.99	0.96	0.94	0.99
	n	0.50	0.44	0.52	0.56	0.58	0.55
	k	1.14	1.15	0.61	0.40	0.23	0.17
10	$r^2$	1.00	0.97	0.95	0.93	0.92	0.83
	n	0.27	0.08	0.01	0.02	0.10	0.25
	k	58.21	78.26	76.10	47.99	24.83	10.24
15	$r^2$	0.99	0.97	0.93	0.94	0.97	0.95
	n	0.24	0.24	0.13	0.02	0.11	0.09
	k	364.31	296.19	349.32	464.05	449.89	294.42
20	$r^2$	0.99	0.98	0.99	0.98	0.98	0.98
	n	0.11	0.04	0.06	0.10	0.18	0.21
	k	838.82	985.35	1174.97	1235.21	1388.53	1210.76

NMFRS: Non-malted-fermented rice + soybean flour, MFRS: Malted-fermented rice + soybean flour,  $r^2$ : Correlation coefficient, n: Flow behaviour index, k: Consistency index

### 3.3 Influence of Activation Energy and Frequency Factor

In Table 6a and 6b the temperature dependency of the viscosity of gruels are shown. Irrespective of concentration or shear rates, the activation energy of the gruels of NMNFRS, MNFRS, NMFRS and MFRS ranged from 5.25 to 28.04 kJmol<sup>-1</sup> (r<sup>2</sup>: 0.87 to 1.00), 12.82 to 37.57 kJmol<sup>-1</sup> (r<sup>2</sup>: 0.91 to 0.99), 5.73 to 32.83 kJmol<sup>-1</sup> (r<sup>2</sup>: 0.89 to 0.99) and 5.73 to 36.97 kJmol<sup>-1</sup> (r<sup>2</sup>: 0.79 to 0.99) respectively. Whereas their corresponding frequency factors ranged from 8.7 × 10<sup>-5</sup> to 1.3 × 10<sup>1</sup>, 1.2 × 10<sup>-7</sup> to 2.4 × 10<sup>-1</sup>, 1.2 × 10<sup>-6</sup> to 1.3 × 10<sup>1</sup> and 6.7 × 10<sup>-7</sup> to 1.2 × 10<sup>1</sup>, respectively. The goodness of fit (r<sup>2</sup>) of the model as observed is high and well correlated throughout.

**Table 6a:** Temperature dependency of the viscosity of gruels

C	γ	NMNFRS		MNFRS		NMFRS		MFRS	
		E <sub>a</sub>	r <sup>2</sup>	E <sub>a</sub>	r <sup>2</sup>	E <sub>a</sub>	r <sup>2</sup>	E <sub>a</sub>	r <sup>2</sup>
5	6	18.52	0.97	22.50	0.99	32.83	0.93	34.67	0.97
	12	17.58	0.87	21.77	0.95	29.03	0.96	30.86	0.94
	30	16.24	1.00	27.60	0.91	26.48	0.97	28.56	0.97
	60	16.79	0.96	34.09	0.92	25.26	0.97	30.64	0.96
10	6	23.40	0.96	34.79	0.97	24.82	0.97	36.97	0.96
	12	25.94	0.99	32.43	0.95	23.76	0.97	25.16	0.95
	30	27.78	0.96	23.75	0.97	25.60	0.99	31.19	0.98
	60	28.04	0.95	24.67	0.93	30.73	0.98	35.39	0.97
15	6	11.55	0.95	25.06	0.96	14.18	0.99	17.43	0.93
	12	16.91	0.97	27.17	0.97	17.00	0.98	16.34	0.87
	30	21.27	0.99	37.57	0.99	28.73	0.99	29.83	0.98
	60	26.32	0.99	32.09	0.98	25.23	0.98	31.42	0.97
20	6	5.67	0.91	12.82	0.98	5.73	0.91	5.73	0.95
	12	5.25	0.94	15.57	0.96	6.18	0.89	10.26	0.79
	30	16.26	0.94	13.90	0.99	14.11	0.94	17.54	0.98
	60	15.21	1.00	17.78	0.97	13.11	0.98	18.72	0.99

NMNFR: Non-malted-non-fermented rice, MNFR: Malted-non-fermented rice, NMFR: Non-malted-fermented rice, MFR: Malted-fermented rice, S: Soybean, C: Concentration (%), γ: Shear rate (revolution per minute), r<sup>2</sup>: Regression coefficient and E<sub>a</sub>: Activation energy.

**Table 6b:** Temperature dependency of the viscosity of gruels

Products	C	γ	NMNFRS	MNFRS	NMFRS	MFRS
			μ <sub>o</sub>			
5	6	6	1.1 × 10 <sup>-3</sup>	1.9 × 10 <sup>-5</sup>	1.2 × 10 <sup>-6</sup>	4.6 × 10 <sup>-7</sup>
		12	9.3 × 10 <sup>-4</sup>	2.0 × 10 <sup>-5</sup>	3.5 × 10 <sup>-6</sup>	1.4 × 10 <sup>-6</sup>
		30	7.4 × 10 <sup>-4</sup>	2.4 × 10 <sup>-6</sup>	5.5 × 10 <sup>-6</sup>	2.1 × 10 <sup>-6</sup>
		60	4.5 × 10 <sup>-4</sup>	1.2 × 10 <sup>-7</sup>	6.0 × 10 <sup>-6</sup>	6.7 × 10 <sup>-7</sup>
10	6	6	1.6 × 10 <sup>-3</sup>	6.7 × 10 <sup>-6</sup>	6.6 × 10 <sup>-4</sup>	5.4 × 10 <sup>-6</sup>
		12	3.5 × 10 <sup>-4</sup>	7.4 × 10 <sup>-6</sup>	7.4 × 10 <sup>-4</sup>	3.3 × 10 <sup>-4</sup>
		30	8.7 × 10 <sup>-5</sup>	8.5 × 10 <sup>-5</sup>	1.6 × 10 <sup>-4</sup>	1.5 × 10 <sup>-5</sup>
		60	4.8 × 10 <sup>-5</sup>	3.0 × 10 <sup>-5</sup>	8.8 × 10 <sup>-6</sup>	1.3 × 10 <sup>-6</sup>
15	6	6	8.6 × 10 <sup>-1</sup>	6.6 × 10 <sup>-4</sup>	2.7 × 10 <sup>-1</sup>	6.1 × 10 <sup>-2</sup>
		12	8.5 × 10 <sup>-2</sup>	1.6 × 10 <sup>-4</sup>	6.1 × 10 <sup>-2</sup>	6.8 × 10 <sup>-2</sup>
		30	5.1 × 10 <sup>-3</sup>	1.6 × 10 <sup>-6</sup>	2.4 × 10 <sup>-4</sup>	1.3 × 10 <sup>-4</sup>
		60	6.1 × 10 <sup>-4</sup>	8.5 × 10 <sup>-6</sup>	7.3 × 10 <sup>-4</sup>	4.8 × 10 <sup>-5</sup>
20	6	6	1.3 × 10 <sup>1</sup>	2.4 × 10 <sup>-1</sup>	1.3 × 10 <sup>1</sup>	1.2 × 10 <sup>1</sup>
		12	0.8 × 10 <sup>1</sup>	6.0 × 10 <sup>-2</sup>	0.5 × 10 <sup>1</sup>	0.1 × 10 <sup>1</sup>
		30	4.1 × 10 <sup>-2</sup>	6.4 × 10 <sup>-2</sup>	8.0 × 10 <sup>-2</sup>	2.2 × 10 <sup>-2</sup>
		60	4.3 × 10 <sup>-2</sup>	1.1 × 10 <sup>-2</sup>	7.6 × 10 <sup>-2</sup>	9.3 × 10 <sup>-3</sup>

NMNFR: Non-malted-non-fermented rice, MNFR: Malted-non-fermented rice, NMFR: Non-malted-fermented rice, MFR: Malted-fermented rice, S: Soybean, C: Concentration (%), γ: Shear rate (revolution per minute) and r<sup>2</sup>: Regression coefficient and μ<sub>o</sub>: frequency factor

The activation energy of gruels mostly decreased with an increase in concentration and also increased with an increase in shear rates, especially from 10 to 20% concentrations. This mean, gruels are less sensitive to temperature change with an increase in concentration and more sensitive to changes with an increase in shear rates. The latter is more complicated, considering viscosity decreases with an increasing shear rate. From the rheological theory and molecular point of view, there is a possibility as the molecules are greatly aligned to oppose flow at higher shear rates than lower shear rates, sensitivity to the temperature measured by the Arrhenius equation may be felt more at higher shear rates. However, lower shear rates always have a greater impact on flow or deformation than higher shear rates. There are still many controversial issues about the mechanics of flows that have not been elucidated. In Table 6b, frequency factors mostly decreased in descending order of magnitude of concentrations (20, 15, 10, and 5% respectively). And this is in line with collision theory. The increase in concentration, temperature or surface area of these food materials would increase the number of collisions of the food molecules to overcome the energy barrier that initiate flow. However, in literature collision theory is more elucidated during chemical reaction than the mechanics of flows. Nonetheless, when molecules collide with one another, they give ways which initiate motion or flow. The more they collide with one another, the more the increase in motion, such as in turbulent flow. It is based on this concept lower shear rates would have greater impact on flow or deformation than the higher shear rates. The activation energy of MFRS was observed to be higher than the NMNFRS. And lower in energy than MNFRS at 5 and 10% concentrations. And also higher in energy than NMFRS at 10, 15, and 20% concentrations. According to the Arrhenius equation, those products at higher activation energy imply more sensitivity to temperature changes at those points (i.e., concentration) than the lower activation energy products. This could mean, that higher activation energy is needed by those products to initiate motion (flow) of the food molecules than the lower ones. In chemistry, a higher value of activation energy substance indicates slow time/high-energy taken reaction (flow). This may be influenced by factors such as enzyme (or catalyst), temperature, surface area etc. Similarly, the NMFRS also followed the same trend. But in this case, activation of NMFRS is higher than the NMNFRS and is also lower than the MNFRS, except at a 20% level of concentration. The activation energy of the MNFRS also followed a similar trend as observed in NMNFRS. However, the quantity of activation energy was observed to be higher in MNFRS compared to NMNFRS.

From the elementary knowledge of chemistry, kinetic energy would increase by decreasing the concentration of molecules. This would explain if the concentration is low (viscosity would be low), molecules will be far apart from each other which will require high energy for collision, so high activation energy. But if concentration is high, molecules will be close to each other and collide faster with ease, so low activation energy. Table 6a at levels of 5 and 20% concentration is a good example for comparison. A high concentration of reactant will also cause more collision and lead to low activation energy. Tables 6a and 6b agreed with this phenomenon as compared, especially the 10, 15 and 20% concentrations. Activation energy which is the energy barrier per mole (Sahin and Sumnu, 2006) enables motion such as in the case of the flow of gruels (reaction such as in the case of acid and base reaction in chemistry) is important for understanding the flow behaviours of substances. From this definition, it can be seen that the textural characteristics which are also one of the determinants for evaluating food quality would depend on the activation energy for mastication or swallowing as well as the flow of food in pipes. Many theories have described how flow occurs (Sahin and Sumnu, 2006; Figura and Teixeira, 2007). One can agree with those assumptions that temperature difference, molecular structure, material with low viscosity and vacancies in liquid are factors that permit flow initiated by activation energy.

Taga and Non (2017) modelled the rheological properties of gruels with concentrations from 15 to 35% w/w, temperature and shear rate from 30 to 60 °C and 0.01 to 250 rpm respectively. Their reports of activation energy within the range of 0.964 to 21.070 kJmol<sup>-1</sup> correspond slightly to the activation energy of non-malted-non-fermented rice + soybean of the 5, 15 or 20% concentration except the 10% which are higher. For malted-non-fermented rice + soybean, only the 20% concentration agreed with their findings. But the non-malted-fermented rice + soybean at 15 or 20% concentration and the malted-fermented rice + soybean at 20% concentration. Sopade and Kassum (1992b) reported higher activation energies of *Kunun zaki* and *Kunun gyada* (complementary food) than all the activation energies of the samples investigated. Also, those of Badau *et al.* (2006) who investigated activation energies of complementary foods as affected by the addition of malt obtained much lower activation energy than in this study. Different studies on 40 different literatures on fruits and vegetables by Krokida *et al.* (2001) are within the range of activation energy obtained in this study except the 20% concentration for non-malted-non-fermented rice + soybean, malted-fermented rice + soybean and non-malted-fermented rice + soybean. In addition, these formulated food products are not pure liquids or chemicals but mixtures of complex substances with differential substantial enzymes. Such that, the slight deviation of some frequency factors or activation energy values versus concentration from trend of kinetic

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theories, depicted the complexity of these foods. Therefore, the flow of these gruels which were mostly influenced by mechanical energy, may not necessarily cause the formation of new gruel products as in the case of a chemical reaction under the influence of chemical properties. But their molecules have changed position by acquiring minimum energy which enables them to begin to flow. Example, at a level of 10% concentration, sample NMNFRS have been initiated with an activation energy of 23.40 kJmol<sup>-1</sup> (Table 5a) which enables it to begin to flow by shearing force of 6 RPM.

#### 4. Conclusion

In this study, the flow responses of the formulated food products (gruels) at temperatures of 30, 40, 50, 60, 70, and 80 °C, and shear rates of 6, 12, 30, and 60 rpm, as well as at each target level concentrations of 5, 10, 15 and 20% have been investigated using standard methods. The effect of malting and/or fermentation, irrespective of the viscosity functions used varied significantly ( $p < 0.05$ ). The highest viscosity reduction was observed in malted-non-fermented rice + soybean (0.01 to 37.50 Nsm<sup>-2</sup>), followed by malted-fermented rice + soybean (0.02 to 110.04 Nsm<sup>-2</sup>), non-malted-fermented rice + soybean (0.23 to 120.10 Nsm<sup>-2</sup>) and non-malted-non-fermented rice + soybean (0.14 to 121.22 Nsm<sup>-2</sup>), respectively. All plots of the viscosities versus shear rates depicted time-independent, non-Newtonian fluids. Viscosity decreased with increasing temperature, and also shear rates as well as increased with increasing concentration. Similar trends were exhibited by the consistency flow behaviour indices of the formulated food products, with all the power-law flow behaviour indices ( $n$ ) being less than 1, which characterized the formulated food gruels as pseudoplastic (shear thinning liquids). Activation energies and frequency factors of the formulated foods, irrespective of the viscosity functions studied ranged from 5.25 to 37.57 kJmol<sup>-1</sup> and  $12 \times 10^{-7}$  to  $1.3 \times 10^1$ , respectively. The regression coefficient ( $r^2$ ) of the linear derivatives of the power law fluids model and the Arrhenius type equation have justified the model parameters appropriately, with  $r^2$  values for the linear correlation obtained being close to 1 or 1, which indicate the models used were accurate for predicting the rheological parameters of these formulated foods. Samples of non-malted-non-fermented rice + soybean (NMNFRS), non-malted-fermented rice + soybean (NMFRS) and malted-fermented rice + soybean (MFRS) are recommended to be prepared at a 15% concentration for infants and malted-non-fermented rice + soybean (MNFRS) at 20% or slightly above 20% concentration for infant feeding (appropriately free-flowing gruel). Also, due to the high demand for rice malt for many food applications at the domestic or industrial level, appropriate de-husking technology for malted rice is required to enhance research studies. Similarly, the steam-cooked form of these products would create an improved instant complementary food.

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