Rheological Properties of Extruded *Fura* from blends of Millet and Cowpea

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ABSTRACT

The rheological properties of *fura* extrudates with different pearl millet and cowpea ratios (80:20, 70:30 and 100% pearl millet flours) were studied. Extrusion cooking was performed in a single screw extruder. Gelatinization temperatures (T_g) were 72 ^oC for Millet: Cowpea (70:30) and 71 ^oC for 100% pearl millet flour indicating that the T_g increased with inclusion of cowpea flour. The time taken to reach gelatinization temperature (Mg) was 27 minutes for 100% pearl millet flour higher than Millet: Cowpea 80:20 and 70:30 flour blends which recorded 25.3 minutes. Gelatinization temperatures for *fura* extrudates were 62, 64.7, 65 and 66.8 ^oC for millet: Cowpea 80:20, 100% traditional fura, millet: Cowpea 70:30 and 100% extruded *fura* respectively. There was general decrease in gelatinization temperature of all products, which can be attributed to previous gelatinization of their starches. There were significant differences in the viscosities of samples at each of the temperature considered from (30^o - 90^{o}C). At 30^{o}C the viscosities ranged from (4.2-17.6 Nsm^{-2}). Traditional *fura* indicated the highest viscosity at all temperatures. The k values increased as the temperature of *fura* samples decreased generally. Flow behaviour for all *fura* samples exhibited non-Newtonian types of fluids at the test conditions since flow behaviour index (n) for each *fura* sample were found to be different from one. Traditional *fura* recorded the highest value for yield stress 18.67 Nm^{-2}, with millet: cowpea 80:20 *fura* recording 8.6 Nm^{-2} as the least value.

INTRODUCTION

In food processing, extrusion cooking provides a great opportunity to create new and exciting products. *Fura,* a traditional thick dough ball snack produced principally from millet or sorghum is very common in West Africa. It is eaten with nono (a local yoghurt) or mashed in water before consumption. Development and processing of high protein *fura* from blends of pearl millet and cowpea has the potential to make a significant impact on the rural economy if properly implemented.

The enrichment or proteinization of *fura*, using available and affordable source of protein, is a good idea for economic growth. Gelatinization and rheological properties of starch are primary physicochemical properties to determine its applications. Key rheological properties of starch include pasting property, viscosity of starch paste, and its rheological features.

Pearl millet (*Pennisetum glaucum* [L.] R.Br.) is grown extensively in the dry areas of western and southern India and along the West African sub region where it is used as food for an estimated 400 million people Hoseney et al.[1] Porridge of millet is made in Eastern Europe, and gruel in countries of Asia and Africa Scherry[2]. The development of an appropriate technology for the traditional products in our fast growing social environment will encourage the acceptability of indigenous traditional foods with great potential for global markets. It is possible to introduce attractive millet foods as extruded millet in western markets.

Flow properties can be used to classify foods into Newtonian and non-Newtonian fluids which may be shear thinning, shear thickening, thixotropic and rheopectic. Such classification is known to be useful in processing, quality control, sensory evaluation, structural analysis and fluid flow and heat transfer analysis. Rheological properties of *fura* are important, as the flow properties influence the dispensability; sensory qualities especially mouth feel and suitable consistency.The objective of this study was to determine the rheological properties of *fura* as influenced by extrusion process and inclusion of cowpea.

MATERIALS AND METHODS

Flour from millet

The process involves dry cleaning of pearl millet grains followed by winnowing using aspirator. The gains were then dehulled after mild wetting of the grain with using the rice dehuller for grains. The grains were washed using plenty water and then dried in an oven at 50ºC for 24 hours to about 14% moisture content. The dried grains were milled using roller mill equipped with a 150µm screen.

Flour from cowpea

Cowpea seeds were steeped in tap water at 28ºC for a period of 30 minutes to loosen the seed coat in a plastic bowl. The kernels were thereafter dried at 50ºC in an oven for 3 hours to approximately 14% moisture content. This was followed by decortications using the traditional pestle and mortar made of wood. The dehulled grain was winnowed using aspirator. The dehulled cowpea grain was ground in the laboratory disc mill. The flour obtained was sieved using a 150µm screen size.

Spices preparation

Black pepper and ginger were sorted and cleaned manually; these were further dried using the convection oven at 60ºC for five hours to dryness. The mass was pounded using the traditional pestle and mortar made of wood. The mass was ground and sieved using a 150µm screen size sieve.

Formulation of feed blends for extrusion

Pearl millet - cowpea supplementation was made by substituting the pearl millet with cowpea at 30 and 20% respectively (pearl millet: cowpea 70:30 and pearl millet: cowpea 80:20). The control sample was made of 100% pearl millet flour. One-percent based spices were added to each sample based on traditional formulation.

Amylogram Determination

Eighty grams of flour and 450 ml distilled water were used with the Brabender amylograph fitted with a pin stirrer. Details of the procedure used were as described in AACC[3] method. Viscosity data was reported in Brabender Units (BU). The Brabender amylograph was used to determine the pasting properties of sample pastes. The sample suspensions or gruel was heated at a controlled rate of 1.5º min^{-1} whilst it was being mixed from ambient temperature to 92ºC and the torque was continuously monitored. It was then held at 92ºC for 15 minutes, followed by cooling at a controlled rate to 52ºC and the pasting history recorded.

Viscosity determination

Viscosity was determined with the aid of rotational viscometer equipped with concentric cylinders. The system has provision for tempering vessel, i.e. connecting a liquid circulation thermostat to the correct temperature is ensured. Viscosity measurement was carried out at 30ºC. Data obtained were fitted to the power law model as described by Clark[4] viscosity relating shear stress (ϒ) with increasing shear rate (γ) is given by the following equation:

$$\Upsilon = k\gamma^n \quad (1)$$

where n = flow index

k = consistency

On linearization the equation becomes:

$$\text{Log}\Upsilon = \text{Log } k + n \text{ Log } \gamma \quad (2)$$

Extrusion condition

Extrusion cooking was performed in a single screw extruder, model (Brabender, Duisburg DCE-330), equipped with a variable speed D-C drive unit, and strain gauge type torque meter. The screw has a linearly tapered rod and 20 equidistantly positioned flights. The extruder was fed manually through a screw operated conical hopper at a speed of 30rpm which ensures the flights of the screw filled and avoiding accumulation of the material in the hopper.

The die is a cone shape channel with 45 degrees entrance angle, a 3mm diameter opening and 90mm length. The screw has a 3:1 compression ratio. The inner barrel is provided with a grooved surface to ensure zero slip at the wall. The barrel is divided into two independent electrically heated zones i.e. (feed end and central zone) cooled by air. There is a third zone at the die barrel, electrically heated but not air cooled. The extruder barrel has a 20mm diameter with lenght to diameter ratio (L:D) of 20:1.

The feed material was fed into a hopper mounted vertically above the end of the extruder which is equipped with a screw rotated at variable speed. The rotating hopper screw kept the feed zone completely filled to achieve a 'choke fed' condition. Experimental samples were collected when steady state was achieved i.e. when the torque variation of plus or minus 0.28 joules (Nm) or about (0.5%) of full scale wass achieved as described Likmani et al[5]. Feed moisture content was kept at 30%, screw speed 180rpm, hopper screw speed 80rpm and barrel temperatures 150°C, 170°C and 150°C for the three heating zones respectively were maintained during extrusion

Statistical analysis

The statistical analysis of (ANOVA) was performed on SAS software, SAS[6]. Significance was defined at ($p \leq 0.05$).

RESULTS AND DISCUSSIONS

Amylograph pasting properties

Table 1, shows the amylograph data for raw samples. The gelatinization temperature (T_g) was 72 °C for Millet: Cowpea (70:30) and 71 °C for 100% pearl millet flour indicating that the T_g increased with inclusion of cowpea flour. Lorenz and Dilsaver[7] reported increase in gelatinization temperature of wheat flours with replacement of wheat flours by millet flours.

Fernandez and Berry[8] reported that, peak viscosities increased for wheat flour when chickpea was present. The peak viscosity for proso millet as reported by Lorenz and Dilsaver[7] was 2500Bu, this decrease as the percentage of wheat flour in the blends increased. The same workers reported that, millet flour milled from the proso Cultivar Turghai showed very similar result of extreme high peak viscosity, which indicates that the proso millet varieties in that study have very low ∝-amylase activity. Adeyemi and Idowu[9] reported that, gelatinization temperature values of 71.2° and 74.4°C for wheat: Corn (40:60) and (60:40) respectively. The time taken to reach gelatinization temperature (Mg) was however more 27 minutes for 100% than Millet: Cowpea 80:20 and 70:30 flour blends which recorded 25.3 minutes.

The peak viscosities (Vm) ranges were 780, 800 and 890 Bu for Millet: Cowpea 70:30, 80:20 and 100% pearl millet flour respectively. The ease of cooking ranged from 6.2 to 9.0 minutes for millet: Cowpea (80:20) and 100% pearl millet flour. Flour of 100% millet indicated highest stability value of 360Bu, when compared to 300Bu for both millet: Cowpea 80:20 and 70:30 flours. The set back (retrogradation) value ranged between 30 to 100Bu for 100% millet flour and both Millet: Cowpea 80:20 and 70:30 flour blends.

The increase in viscosity during the cooling period is indicative not only the normal inverse relationship between the viscosity and temperature of suspensions but also of the tendency for various constituents present in the hot paste (swollen granules, fragments of swollen granules, and colloidally dispersed and dissolved starch molecules) to associate or retrograde as the temperature of the paste decreases.

The height of the peak at a given concentration reflects the ability of the granules to swell freely before their physical breakdown. Starches that are capable of swelling to a high degree are also less resistant to breakdown on cooking and hence exhibit viscosity decreases significantly after reaching the maximum value. There was an increase in the retrogradation value for samples blended with Cowpea compared to 100% millet flour. Okaka and Isieh[12] reported similar, results of Cowpea-wheat formulations.

The pasting history of products is presented in Table 2. Gelatinization temperatures ranged from 62°C for millet: Cowpea 80:20 to 66.8 °C to 10% extruded *fura*. Millet: Cowpea (80:20) had the lowest gelatinization temperature (62°C). ANOVA result revealed that peak viscosity of the traditional *fura* was significantly different ($p \leq 0.05$) from the values of extrudates.

There was considerable reduction in the peak viscosities of all products; this is probably because of previous gelatinization of their starches. Adeyemi and Beckley[11] reported that a high level of damaged starch would reduce peak viscosity of flour or ogi. The high retrogradation value recorded by traditional *fura* gives an indication of high level of reassociation of its starch molecules into an ordered structure after processing; this is attributed to less damage to its starch compared to *fura* extrudates. Gomez et al[12] reported that a loss of crystalline organization of starch and the simultaneous reorganization of the gelatinized macromolecules during extrusion occurs by different mechanisms than it does during the classical gelatinization of starch in aqueous system.

<u>Viscosity and flow indices</u>

Table 3, reveals the responses of 10% slurries of products' dynamic viscosities with temperature variation. Physical properties of foods play an important role in consumer acceptance. Appearance, size, shape, texture, consistency, viscosity and mouthfeel are all important in food acceptance, Wijeratne[13].

Traditional *fura* indicated the highest viscosity at all temperatures. As would be expected viscosities of samples decreased with increase in temperature. Lewis[14] reported that, all liquids decrease in viscosity as the temperature increases. Gruels from rehydrated extruded cooked products usually have high viscosity and required dilution with water to achieve appropriate consistency for feeding Likimani[5].

Extrusion usually induced starch dextrinization results in reduction of viscosity in all gruels and a concomitant increase in Caloric and nutrient density Jansen et al[15]. Bhattacharya et al[16] reported that, viscosity of protein would depend on solubility and water holding capacity as well as the structure. Globular structures can be expected to be more viscous than the linear structures. Arambular et al[17] reported decreased apparent viscosity of extruded instant corn flour when temperature was increased.

Davidson et al[18] reported that viscosity over a heating and cooling cycle have been used to characterize the changes in extruded products in numerous studies. They further reported that, the characteristics of the paste viscosity curves were significantly altered by extrusion processing with extrudates showing low values. The consistency coefficient (k) and flow behaviour index (n) values are presented in Table 4. The k values increased as the temperature of *fura* samples decreased generally. Since the k value has a direct relationship with viscosity (power law equation 1.), it can be used to represent the viscosity characteristics of a material under certain conditions. The consistency index for traditional *fura* was higher among the *fura* samples and differed significantly ($p \leq 0.05$) from the other *fura* samples. At any temperature, consistency index values were higher for traditional *fura.* The k values for *fura* samples produced from blends of pearl millet and cowpea were higher for *fura* samples made from 100% millet extrudates.

Flow behaviour for all *fura* samples exhibited non-Newtonian types of fluids at the test conditions since flow behaviour index (n) for each *fura* sample were found to be different from one, Lewis[14]. Values ranged from 0.16 to 0.58 for all the samples studied, suggesting pseudoplastic type of flow. The consistency index k is a strong function of the concentration of the solution and the temperature, where flow index n does not have a strong dependence on the concentration and temperature of polymeric solution Gomez-Diaz and Navaza[19].

Activation energy, Arrhenius constant and yield stress.

The data on the temperature-dependence of the consistency factors was analysed using an Arrhenius equation:

$k=k_o \exp(- E_a/RT)$, (3)

Where k_o = consistency index at a reference temperature ($T = \infty$); E_a = activation energy; R = universal gas constant; T= absolute temperature.

On linearization;

$\text{Ink}= \ln k_o - (E_a/R)(1/T)$. (4)

From the plot of Ink against (1/T), the activation energy was obtained and the sensitivity of the consistency index to temperature evaluated. The results of yield stress and activation energy are presented in Table 5. Traditional *fura* recorded the highest value for yield stress 18.67 Nm^{-2}, with millet: cowpea 80:20 *fura* recording 8.6 Nm^{-2} as the least value. Higher yield stress translates to higher energy required for mastication during chewing.The values of the activation energy E_a ranged from 28.44 Kj mol^{-1} for 100% traditional *fura* to 68.64 Kj mol^{-1} for millet: cowpea (80:20) *fura* extrudate. Millet: cowpea (80:20) had the highest E_a 68.64 Kj mol^{-1} and more sensitive to temperature change. On the other hand traditional *fura* had the least E_a 28.44 Kj mol^{-1} and therefore means it has least temperature sensitivity changes. The activation energy can give an indication of relative sensitivity of viscosity with temperature change. The higher the E_a, the less is the effect of temperature on the viscosity of a product.

CONCLUSION

This study has provided information on the rheological behviour of extruded *fura* in comparison to traditional *fura.* The rheological responses of all *fura* samples is pseudoplastic i.e. they exhibited shear thinning effect with the power law index n ($0 < n < 1$). The result has equally shown that retrogradation value for extruded *fura* is quite low when compared with traditionally prepared *fura* which is an indication of stability. Inclusion of soybean, cowpea and groundnut did not influence the viscosities of extruded *fura* samples significantly on a general note. From the results of viscosity it shows that effect of temperature on the extrudates was narrow. Traditional *fura* showed least sensitivity to temperature changes, for quality control considerations this should be noted.

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Table 1: Brabender Amylograph pasting parameters of raw sample

Samples	Tg (^{0}c)	Mg (Min)	Vm (Bu)	Mn (Min)	Vr (Bu)	Ve (Bu)	Mn-Mg (Min)	Vm-Vr (Bu)	Ve-Vm (Bu)	Ve-Vr (Bu
Millet:: Cowpea80:20										
70:30	71.60± 0.02	25.3 ± 0.12	800 ± 0.4	31.5 ± 0.16	500 ± 0.16	900±0.5	6.2 ± 0.34	300 ± 0.3	100± 0.71	400 ± 0.16
100%	72.00± 0.01	25.3 ± 0.31	780± 0.13	31.8 ± 0.2	480 ± 0.73	880±0.1	6.5 ± 0.28	300 ± 0.23	100 ± 0.34	400 ± 0.23
Millet Flour										
	71.0 ± 0.64	27.0 ± 0.12	890 ± 0.24	36 ± 0.41	530 ± 0.32	920±0.03	9.0 ± 0.6	360 ± 0.34	30 ± 0.35	390 ± 0.64

Table 2: Brabender Amylograph pasting parameters of Products

Samples	Tg (^{0}c)	Mg (Min)	Vm (Bu)	Mn (Min)	Vr (Bu)	Ve (Bu)	Mn-Mg (Min)	Vm-Vr (Bu)	Ve-Vm (Bu)	Ve-Vr (Bu)
Millet:: Cowpea										
80:20	62±0.91	22.5 ± 0.8	80 ± 0.13	34.5 ± 0.7	20 ± 0.4	25 ± 0.23	12.0 ± 0.69	60.0 ± 0.16	-55 ± o.34	5 ± 0.14
70:30	65±0.64	22.0 ± 0.4	90 ± 0.42	35.0 ± 0.8	20±0.34	30 ± 0.43	13.0 ± 0.36	70.0 ± 0.32	-60 ± 0.64	10 ± 0.13
100%										
Millet *Fura*	66.8±0.24	24.0 ± 0.7	160±0.13	33.5 ± 0.43	70 ± 0.6	120±0.64	9.5 ± 0.64	90.0 ± 0.45	-40 ± 0.16	50 ± 0.68
Extruded	64.7 ± 0.2	20.0 ± 0.81	80 ± 0.24	38 ± 0.43	90 ± 0.8	250±0.38	18.0 ± 0.31	-10.0 ± 0.54	170 ± 0.23	160 ± 0.96
Traditional										

Values are means of duplicate determinations:
Tg (^{o}C): Gelatinization temperature; Mg (min): Time taken for gelatinization;Vm (Bu): Peak viscosity;Vr (Bu): Viscosity after 15 minutes at 92^{o}C;Mn (mins): Time taken to reach peak viscosityVe (Bu): Viscosity on cooling to 52^{o}C ;Mn-Mg (Min): Ease of Cooking;Vm-Vr (Bu): Stability of starch;Ve-Vm (Bu): Set back value;Ve-Vr (Bu): Index of gelatinization

Table 3: Effect of temperature on the Viscosity of 10% Slurry of products

Samples	Apparent Viscosity Nsm^{-2}						
	30^0C	40^0C	50^0C	60^0C	70^0C	80^0C	90^0C
Millet: Cowpea							
80:20	8.1 ± 0.14^c	5.7 ± 0.16^d	4.8 ± 0.05^d	4.0 ± 0.08^{de}	3.7 ± 0.1^c	3.3 ± 0.11^c	2.7 ± 0.04^c
70:30	15 ± 0.11^b	12 ± 0.09^b	11.0 ± 0.08^b	7.6 ± 0.05^b	6.7 ± 0.16^b	5.2 ± 0.14^b	4.6 ± 0.14^b
100% Millet *Fura*							
Extruded	7.1 ± 0.22^d	6.2 ± 0.09^{cd}	6.2 ± 0.14^c	5.7 ± 0.18^d	4.6 ± 0.14^c	3.8 ± 0.07^c	3.3 ± 0.05^c
Traditional	17.6 ± 0.16^a	15.4 ± 0.02^a	14.2 ± 0.14^a	13.0 ± 0.28^a	12.0 ± 0.08^a	9.8 ± 0.09^a	7.6 ± 0.07^a

Means within a column not having same superscript are significantly different ($P<0.05$) values are means of triplicate determinations

Table 4: Effects of temperature on consistency index (k) and flow index (n) of 5% gruels of *fura* samples

Samples	30^oC		40^oC		50^oC		60^oC		70^oC	
	k	n	k	n	k	n	k	n	k	n
Millet: Cowpea										
80: 20	8.1	0.53	7.6	0.56	6.3	0.54	5.3	0.46	3.1	0.50
70:30	8.6	0.54	7.8	0.58	6.7	0.52	5.6	0.52	3.3	0.51
100% Millet										
Extruded *Fura*	16.5	0.45	12.3	0.48	10.6	0.52	9.10	0.48	5.30	0.47
Traditional *Fura*	43.56	0.23	34.23	0.17	23.21	0.20	18.24	0.16	12.67	0.21

Table 5: Arrhenius constant (K_o) and activation energy (E_a) of cooked 5% slurry of samples

Samples	*Yield stress (Nsm^{-2})	E_a (kJ/mol)	Correlation coefficient (r)
Millet: Cowpea			
80:20	8.6	68.64	0 .945
70:30	9.1	42.31	0.943
100% Millet			
Extruded *Fura*	10.87	28.53	0.958
Traditional *Fura*	18.67	28.44	0.977

*Measured at 30^oC