The Rheological Profile of Cereal Flour Composites as affected by Gamma Irradiation

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Research Article

Abstract: Retrogradation of starch occurs when the amylose in starch-containing products returns to a less soluble, crystalline state over time. Irradiation has been shown to be a useful method for producing modified starch since it generates free radicals that can alter the structure of starch molecules. The aim of this work was to enhanced cereal flour composite using gamma irradiation to be used as breakfast meal. Cereal flour composites were prepared from three local cereals wheat, sorghum and rice in a certain ratio and gamma irradiated for subsequent analysis. Pasting properties and moisture were analyzed. The irradiated flour composite showed decreases in maximum viscosity temperature, maximum viscosity, cooling and final holding viscosities, setback viscosity, breakdown viscosity and retrogradation. The irradiation and the composite ratio had significant effect on all the pasting parameters studied except the beginning gelatinization torque. Cereal breakfast meal could be preferably prepared from irradiated wheat, sorghum and rice flours in the ratios of 25 % wheat: 25 % sorghum: 50 % rice or 100 % each of wheat, sorghum and rice or 25 % wheat: 50 % sorghum: 25 % rice.

Keywords: Flour composite, retrogradation, cereals, irradiation, rheological.

1.0 Introduction

Porridge refers to hot cereal grains or ground legumes boiled in water or milk, and often served as a breakfast food. Almost every household in Ghana takes porridge ("Koko") as breakfast. The cereal flour composite of the porridge is dependent on the individual preference for which most of them are single-cereal based that are normally made of corn/maize or sorghum, millet or wheat. In Ghana, sometimes some herbal spices are added to give taste/flavor and this porridge is known as "Hausa Koko". Gelatinization is the disruption of molecular order of the starch polymers and occurs first, whilst pasting refers more to the evidence of the disruption of molecular order such as viscosity development (Nelles *et al.,* 2000). Gelation of starch is dependent on the amylose/amylopectin ratio which determines the rheological property (viscosity and deformation) of a product (Cuevas *et al.,* 1985). This involves granular swelling, exudation of molecular components from the granule, and eventually total disruption of the granules. The rate and extent of starch retrogradation is affected by the length of time a product is stored and the temperature of storage (Longton and LeGrys, 1981; Eliasson, 1983; Nakazawa *et al.,* 1985). Irradiation has been shown to be a useful method for producing modified starch since it generates free radicals that can alter the structure of starch molecules (Sokhey and Hanna, 1993). The major effect of gamma irradiation on starch has been reported to be depolymerizing or degrading starch chains, resulting in progressive reduction in molecular size of amylose and amylopectin (Sokhey and Hanna, 1993; Tomasik and Zaranyika, 1995). The aim of this work was to enhanced cereal flour composite using gamma irradiation to be used as breakfast meal.

2.0 Materials and Methods

2.1. Sample collection and preparation

Three local cereals; Wheat (**W**), Rice (**R**) and Sorghum (**S**) were bought from a local market in Accra, Ghana. The cereal grains were screened to eliminate the bad ones and foreign materials. They were then dry-milled into flours using a hammer mill (Brook Crompton, Huddersfield, England) through a 250 mm sieve. Percentage flour composites (A, B and C) were established and packaged in the ratios: **A** (100**W**: 100**S**: 100**R**), **B** (25**W**: 25**S**: 50**R**) and **C** (25**W**: 50**S**: 25**R**) and sealed in labelled polyethylene bags and sent for irradiation. The samples were irradiated using a gamma irradiation facility of cobalt 60 source (SLL-515, Hungary) at the Radiation Technology Centre (RTC) of the Ghana Atomic Energy Commission (GAEC). The radiation doses used were 0.0, 2.5, 5.0, 7.5 and 10 kGy at a dose rate of 2.05 $kGyhr^{-1}$ in the shredded area and the absorbed dose confirmed by Fricke's dosimetry, and the flour stored in a refrigerator at 4 ^{o}C prior to analysis.

2.2 Sample analyses

2.2.1. Moisture content

The moisture contents of the flour samples were measured using the Denver Instrument IR-60 Moisture Analyzer which uses infra-red ray. The moisture analyzer was programmed to give the same results as the standard method. The moisture analyzer consists of two important components; a balance and a heater. Two grams of the sample was placed in the moisture analyzer and the balance captured the initial weight. The infrared energy heater was used to heat the sample and during the test the balance recorded the weight. When the sample was no longer losing weight the instrument shut off the heat and used the final weight to calculate moisture. The value of the moisture content was displayed on the screen which was then recorded.

2.2.2. Rheological Profile

The pasting profiles of the composite flour were determined as follows. The mean moisture content of the test sample was determined using the Denver Instrument (IR-60) as described in 2.2.1. The information of sample and operator were fed into the window interface of the Brabender Viscograph-E (Brabender GmbH & Co. KG, Germany) as well as the mean moisture content of the sample. The software requires 40g of moisture-free sample, which is to be mixed with 420 ml of clean tap water to form a suspension in large beaker. Once the moisture content of the sample was fed into the windows interface of the software, the corrected weight (more than 40 g) of the test sample to be weighed and the volume (less than 420 ml) of tap water to be measured were automatically generated. The equipment was programmed to run at a speed of seventy-five (75) revolution per minute with a measuring range of 700 cmg. The temperature profile of the analysis was programmed to commence measurement at a temperature of 50 ^{o}C with heating at the rate of 3 ^{o}C per minute up to a temperature of 92 ^{o}C. The temperature of the sample was held constant for fifteen (15) minutes and then cooled at the rate of 3 ^{o}C per minute to a temperature of 55 ^{o}C. This temperature was also held constant for fifteen (15) minutes. The suspension of the starch containing sample was mixed thoroughly and poured into the measuring bowl of the Brabender Viscograph-E. The test was then started by clicking on the start button on the windows interface and then lowering the measuring head into the measuring bowl. After running the equipment, the following data could be obtained from the test: the time, temperature and viscosity at the beginning of gelatinization, maximum viscosity, start of holding period, start of cooling period, end of cooling period, and at the end of final holding period as well as breakdown and set back viscosities.

2.2.3. Statistical Analysis

All analyses were done in triplicates. Two-way Analysis of variance was done using StatGraphics Centurion XVI.I Statistical Software Program. The least significant difference test (LSD-test) was applied. The level of significance used was 95% ($p < 0.05$). Correlation between the dosage, composite and all the pasting parameters was obtained.

3.0 Results and Discussion

3.1 Moisture content of flour composite

Table 1: Moisture Content of Flour (%)

DOSE (KGY)	COMPOSITE (%)		
	A	B	C
0.0	$12.380 \pm 0.121_a^x$	$11.887 \pm 0.121_a^x$	$12.583 \pm 0.121_a^x$
2.5	$12.287 \pm 0.121_a^x$	$12.270 \pm 0.121_a^x$	$12.130 \pm 0.121_a^x$
5.0	$11.733 \pm 0.121_a^x$	$12.450 \pm 0.121_a^x$	$12.157 \pm 0.121_a^x$
7.5	$12.287 \pm 0.121_a^x$	$12.450 \pm 0.121_a^x$	$12.130 \pm 0.121_a^x$
10.0	$12.240 \pm 0.121_a^x$	$12.457 \pm 0.121_a^x$	$12.113 \pm 0.121_a^x$

Values within each column (dosage) with different subscripts are significantly different ($p < 0.05$) and values within each row (composite) with different superscripts are significantly different ($p < 0.05$).

There were no significant differences ($p < 0.05$) in the moisture content across both the composites and the dosages used. This is an indication that both the irradiation and the percentage composition of the cereals did not cause changes in the moisture content of the composites. This is evidenced by the correlation (r = -0.1755 and -0.0383) obtained for moisture content, irradiation dose and composite respectively. Findings of A/Azim *et al*. (2009) and Rady *et al*. (2002) revealed that irradiation has no effect on the moisture contents of oil seeds. Darfour *et.al* (2012) and Nunoo (2009) also had similar observations on some irradiated leguminous seeds. During radiation processing, the moisture content of the sample is of utmost importance as it controls the net radiochemical changes (Wilkinson and Gould, 1998).

3.2 Beginning of Gelatinization Torque

Table 2: Beginning of Gelatinization Torque (BGTo)

DOSE (KGy)	COMPOSITE (BU)		
	A	B	C
0.0	$19.00 \pm 0.323_a^x$	$19.00 \pm 0.323_a^x$	$19.00 \pm 0.323_a^x$
2.5	$19.00 \pm 0.323_a^x$	$19.50 \pm 0.323_a^x$	$19.00 \pm 0.323_a^x$
5.0	$19.50 \pm 0.323_a^x$	$18.00 \pm 0.323_a^x$	$19.50 \pm 0.323_a^x$
7.5	$18.50 \pm 0.323_a^x$	$18.00 \pm 0.323_a^x$	$20.00 \pm 0.323_a^x$
10.0	$20.00 \pm 0.323_a^x$	$18.00 \pm 0.323_a^x$	$18.50 \pm 0.323_a^x$

Values within each column (dosage) with different subscripts are significantly different ($p < 0.05$) and values within each row (composite) with different superscripts are significantly different ($p < 0.05$).

The viscosities of both the irradiated and un-irradiated samples were not significantly different and the composites were not significantly different from each other in gelatinization torque at the beginning. This means the irradiation dose and the composites did not have any effect on the torque at the beginning. The transition from a suspension of starch granules to a paste, when heat is applied, is accompanied by a large increase in viscosity.

3.3 Maximum Viscosity and Temperature

Table 3: Maximum Viscosity (MV)

DOSE (KGy)	COMPOSITE (BU)		
	A	B	C
0.0	$275.00 \pm 1.291_a^y$	$218.50 \pm 1.291_a^z$	$325.00 \pm 1.291_a^x$
2.5	$166.50 \pm 1.291_b^y$	$136.50 \pm 1.291_b^z$	$183.50 \pm 1.291_b^x$
5.0	$83.50 \pm 1.291_c^y$	$81.00 \pm 1.291_c^z$	$93.50 \pm 1.291_c^x$
7.5	$75.50 \pm 1.291_d^y$	$72.50 \pm 1.291_d^z$	$78.50 \pm 1.291_d^x$
10.0	$76.50 \pm 1.291_d^y$	$73.50 \pm 1.291_d^z$	$79.00 \pm 1.291_d^x$

Values within each column (dosage) with different subscripts are significantly different ($p < 0.05$) and values within each row (composite) with different superscripts are significantly different ($p < 0.05$).

The maximum viscosities of the irradiated composites were significantly lower than the un-irradiated and it significantly decreased with the irradiation dose. Significant decreases in the maximum viscosities were orderly observed in samples C, A and B, hence sample B had the lowest maximum viscosity. As the dosage of irradiation is increased, the viscosity decreased. These drastic reductions in viscosity for the gamma irradiated flour were caused by cleavage of the glycosidic bonds through free radical formation to form smaller carbohydrate units or dextrins of varying lengths, leading to a reduction in the molecular weight (Urbain, 1986) and solubility increase (MacArthur and D'Appolonia, 1984). Ionizing radiation causes scission in the glycosidic chains randomly. Therefore, scissions of the chains probably produce short amylose chains, short linear chains from the branches of amylopectin or small-branched fraction of the amylopectin. Starch granules loss their ability to swell during cooking and therefore no significant imbibition of water occurred. Maximum viscosity reflects the ability of starch granules to swell freely before their physical breakdown. This means that composites C, A, and B had increases in the swelling ability of the pastes but increasing the irradiation dose reduced the swelling ability. The observations that irradiation cause a reduction in maximum viscosity were also made by Rao *et al.* (1978), Rao and Vakil (1985), Marathe *et al.* (2002), Mohd *et al.* (2009), A/Azim *et al.* (2009) and Darfour *et al.* (2012). Maximum viscosity relates with product quality hence significant differences observed among the samples studied may influence their performance and preference in product development such as porridge preparation. The higher maximum viscosity associated with the composite C might be related to the proportion of starch in the flour the ratio of amylose to amylopectin and the ability of its starch granules to swelling.

Table 4: Maximum Viscosity Temperature (MVTe)

DOSE (KGy)	COMPOSITE (BU)		
	A	B	C
0.0	$92.85 \pm 0.153_a^{xy}$	$92.45 \pm 0.153_a^y$	$93.00 \pm 0.153_a^x$
2.5	$91.30 \pm 0.153_b^y$	$91.10 \pm 0.153_b^{yz}$	$91.60 \pm 0.153_b^x$
5.0	$90.10 \pm 0.153_c^x$	$89.55 \pm 0.153_c^y$	$90.05 \pm 0.153_c^{xy}$
7.5	$89.65 \pm 0.153_d^{xy}$	$89.30 \pm 0.153_d^{yz}$	$88.45 \pm 0.153_d^z$
10.0	$89.80 \pm 0.153_d^{xy}$	$89.30 \pm 0.153_d^{yz}$	$88.50 \pm 0.153_d^z$

Values within each column (dosage) with different subscripts are significantly different ($p < 0.05$) and values within each row (composite) with different superscripts are significantly different ($p < 0.05$).

The maximum temperatures of the irradiated composites were significantly lower than the un-irradiated with increasing dose. This may be attributed to stronger hydrogen bonding in the un-irradiated flour starch than the irradiated since the radiation have weakened the bonds in the irradiated flour starch. The maximum viscosity temperature was significantly correlated to the maximum viscosity torque (r = 94 %). This means the lower the maximum viscosity the lower the temperature used. The reduction in maximum viscosity temperature is important in the conservation of energy consumption during the preparation of porridge.

3.4 End of Cooling and Final Holding Periods Torque

Table 5: End of cooling and Final Holding Period Torque (EFHPTo)

DOSE (KGy)	COMPOSITE (BU)		
	A	B	C
0.0	$473.50 \pm 2.720_a^y$	$359.00 \pm 2.720_a^z$	$597.00 \pm 2.720_a^x$
2.5	$276.50 \pm 2.720_b^y$	212.50 ±	$311.00 \pm 2.720_b^x$
5.0	$119.00 \pm 2.720_c^y$	2.720_b^z	$134.00 \pm 2.720_c^x$
7.5	$104.20 \pm 2.720_d^y$	$106.50 \pm 2.720_c^z$	$104.00 \pm 2.720_d^x$
10.0	$102.50 \pm 2.720_d^y$	$94.00 \pm 2.720_d^z$	$104.50 \pm 2.720_d^x$
		$92.50 \pm 2.720_d^z$	

Values within each column (dosage) with different subscripts are significantly different ($p < 0.05$) and values within each row (composite) with different superscripts are significantly different ($p < 0.05$).

The end of final holding period viscosity (EFHPTo) decreased significantly with increasing radiation dose with the un-irradiated been the highest. The EFHPTo of the composites significantly decreased from the C, A to B. The most commonly used parameter to determine starch-based samples quality is final viscosity, it indicates starch/flour ability to form a gel after cooking. Final viscosity is the viscosity after cooling cooked paste to 50 ^oC. The final viscosities values are comparatively significantly higher than the maximum viscosities values due to the high degree of association between starch-water systems and their high ability to re-crystallize, resulting in progressively higher viscosities during cooling of starches (Ayernor, 1985). Final viscosity (indicates the ability of the flour to form a viscous paste). The increase in viscosity which occurs as a result of cooling is mainly due to re-association between starch molecules, especially amylose. The results of the final viscosity suggest that the proportion of starch (amylose) content re-association in the un-irradiated samples is considerably higher than the irradiated samples. Therefore, the irradiated samples with increasing dose are less viscous upon cooling so as B, A and C respectively.

3.5 Breakdown Viscosity

Table 6: Breakdown Viscosity (BDVTo)

DOSE (KGy)	COMPOSITE (BU)		
	A	B	C
0.0	$62.00 \pm 1.658_a^y$	$49.00 \pm 1.658_a^z$	$70.00 \pm 1.658_a^x$
2.5	$57.00 \pm 1.658_b^y$	$39.00 \pm 1.658_b^z$	$64.50 \pm 1.658_b^x$
5.0	$39.50 \pm 1.658_c^y$	$38.50 \pm 1.658_c^z$	$43.50 \pm 1.658_c^x$
7.5	$36.60 \pm 1.658_d^y$	$35.75 \pm 1.658_d^z$	$36.75 \pm 1.658_d^x$
10.0	$35.00 \pm 1.658_d^y$	$34.00 \pm 1.658_d^z$	$37.00 \pm 1.658_d^x$

Values within each column (dosage) with different subscripts are significantly different ($p < 0.05$) and values within each row (composite) with different superscripts are significantly different ($p < 0.05$).

There were significant decreases in the breakdown viscosity in the order of composite C, A and B and significant decrease in the breakdown viscosity in the irradiated samples with increasing dose (r = -63%). The higher breakdown of viscosity of the un-irradiated flour indicates considerable disruption or weakening of the bonding forces (hydrogen bonds) in the starch granules during heating (Barimah *et. al.*, 2009). The lower breakdown of viscosity during heating indicates good stability of the starch granules (Adebowale *et al*., 2005 and Zobel, 1984). This indicates that composite B had the best starch stability followed by A and C and the starch stability correspondingly increased with the irradiation dose for all the composites. This implies that the irradiated flour composites are more stable to heat and mechanical shear than the un-irradiated and these increased with the radiation dose. Similar observations were made by Darfour *et al.* (2012), Barimah *et al.* (2009), Nunoo (2009) and Mohd *et al*. (2009) using irradiated flour samples. Breakdown viscosity and maximum viscosity are positively correlated (r = 69 %).

3.6 Setback viscosity

Table 7: Setback Viscosity (SBVTo)

DOSE (KGy)	COMPOSITE (BU)		
	A	B	C
0.0	$351.0 \pm 2.865_a^y$	$253.00 \pm 2.865_a^z$	$412.50 \pm 2.865_a^x$
2.5	$206.0 \pm 2.865_b^y$	$150.50 \pm 2.865_b^z$	$231.50 \pm 1.658_b^x$
5.0	$81.0 \pm 2.865_c^y$	$67.50 \pm 2.865_c^z$	$89.00 \pm 2.865_c^x$
7.5	$63.0 \pm 2.865_d^y$	$55.50 \pm 2.865_d^z$	$66.50 \pm 2.865_d^x$
10.0	$41.0 \pm 2.865_e^y$	$45.50 \pm 2.865_e^z$	$59.50 \pm 2.865_e^x$

Values within each column (dosage) with different subscripts are significantly different ($p < 0.05$) and values within each row (composite) with different superscripts are significantly different ($p< 0.05$).

There were significant decreases in the setback viscosity in the order of composite C, A and B and significant decrease in the setback viscosity in the irradiated samples with increasing dose (r = -91 %). Setback shows the cold paste viscosity's tendency to retrograde (Shelton and Lee, 2000). Therefore, the lower setback viscosity of the irradiated samples indicates that the reassociation of the starch polymers is not as great as in the un-irradiated flour. Pomeranz (1991) established that high setback (retrogradation) will cause undesirable gel texture or high syneresis (the leakage of water) and low freeze-thaw stability. Setback viscosity is an important factor used in food processing and preservation because food's deterioration depends on the rate of retrogradation. The lower setback value obtained for composite B and all the irradiated samples suggested a reduction in retrogradation tendency. The lower setback suggests that the starch is relatively more stable when cooked and will have a lower tendency to undergo retrogradation during freeze/thaw cycles. Sanni *et al*., (2001) also reported that lower setback viscosity during cooling indicated higher resistance to retrogradation. These changes may affect the physical and rheological properties of irradiated starches, resulting in changes in properties of starch paste (Mohd *et al*., 2009). Therefore, the irradiated cereal flour samples would have reduced starch retrogradation. Retrogradation of amylose was possibly inhibited by the small fractions of cleaved amylopectin. The decreases in breakdown and setback viscosities induced by the irradiation may respectively present opportunities such as ease of cooking and reduced starch retrogradation in porridge preparation. Setback viscosity is positively correlated to maximum viscosity (r = 99.8 %) and breakdown viscosity (r = 72 %).

Table 8: Correlations between all the rheological parameters

BGTo	-0.165									
MVTo	-0.910	0.199								
MVTe	-0.956	0.290	0.943							
SHPTo	-0.916	0.202	0.999	0.947						
SCPTo	-0.902	0.188	0.992	0.933	0.991					
ECPTo	-0.908	0.206	0.999	0.943	0.999	0.994				
EFHPTo	-0.894	0.202	0.999	0.934	0.998	0.988	0.998			
BDVTo	-0.633	0.187	0.687	0.672	0.690	0.593	0.676	0.699		
SBVTo	-0.906	0.216	0.998	0.945	0.998	0.984	0.997	0.997	0.724	
	DOSE	BGTo	MVTo	MVTe	SHPTo	SCPTo	ECPTo	EFHPTo	BDVTo	SBVTo

4.0 Conclusion

The irradiated cereal flour composites showed decreases in maximum viscosity temperature, maximum viscosity, cooling and final holding viscosities, setback viscosity, breakdown viscosity and retrogradation. The irradiation and the flour composite ratio had significant effect on all the pasting parameters studied except the beginning gelatinization torque. In terms of low retrogradation, stability to heat, less viscosity and low energy consumption the irradiated flours and composites B, A and C (in decreasing order) are preferable. However, if swelling alone was to be considered then the irradiated flour composites C, A and B (decreasing in preference) and all the non-irradiated flour composites are preferable. Generally, the best cereal flour composite for breakfast preparation could be preferably prepared from irradiated wheat, sorghum and rice flours in the ratios of 25 % wheat: 25 % sorghum: 50 % rice or 100 % each of wheat, sorghum and rice or 25 % wheat: 50 % sorghum: 25 % rice.

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