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FUNCTIONAL AND ANTIOXIDATIVE PROPERTIES OF SORGHUM *OGI* FLOUR ENRICHED WITH COCOA

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Abstract
This study was carried out to determine the functional and antioxidative properties of blends of sorghum ogi flour and cocoa powder. The blends were produced by adding cocoa powder in proportional gradients of 0, 10, 20, 30, 40 and 50% to sorghum ogi. The pH, total titratable acidity, bulk density, oil absorption capacity and least gelation concentration of the resulting samples as determined were 4.13 to 6.69, 0.109 to 0.198%, 0.515 to 0.646 g/mL, 133.50 to 144.24% and 6 to 12%, respectively. The swelling power and solubility of the blends decreased with the inclusion of cocoa powder but increased with increase in temperature upon evaluation. The water absorption capacity increased with addition of cocoa powder and increase in temperature. The extent of relationship of the swelling power, solubility and water absorption capacity of all the samples, control sample (100% ogi sample) inclusive, to temperature was found to be polynomial in nature. The antioxidative activities (DPPH radical scavenging ability, ferric reducing ability, metal chelating ability and total phenolic content) of the blends also increased proportionately with increase in the inclusion of cocoa powder. The study established that the inclusion of cocoa powder enhanced the functional and antioxidative properties of the enriched sorghum ogi samples.

Keywords: Sorghum *ogi*, functional properties, antioxidative properties, cocoa enrichment

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INTRODUCTION

Sorghum *ogi* is among the staples of the populace in Nigeria and some other African countries. This fermented cereal product is also known as *akamu*, *uji* and *akosa* in Southeast Nigeria, Kenya and Ghana, respectively (Adegbehingbe, 2014). It is largely consumed by children, adults, and recuperating patients. It is used as a weaning food. Despite its widespread consumption, unfortunately it is nutritionally deficient in terms of nutrients like protein and minerals (Afolayan *et al*., 2010). Reports indicated that, sorghum *ogi* has high percentage (70.50 to 79.35%) of carbohydrate (Oyarekua and Eleyinmi, 2004; Akanbi *et al*., 2010).

Several published reports (Akanbi *et al*., 2003; Ajanaku *et al*., 2012, 2013) have centred on improving the nutritional values of the food through enrichment most especially with protein rich substances to boost limiting amino acids in sorghum *ogi* (Fasasi *et al*., 2007). The limiting amino acids in sorghum grain are however present in cocoa powder; the mix of cocoa powder and sorghum *ogi* would therefore be complementary. There is currently no published information on the functional and antioxidative properties of this blend.

Cocoa powder is rich in protein, minerals and antioxidants (Lee *et al*., 2003). It is largely utilized for beverage and confectioneries production. Its expanded usage in sorghum *ogi* is yet to be explored or reported. Increasing malnutrition indices and the need to expand gross domestic products therefore necessitated for the evaluation of the probable utilization of cocoa powder in sorghum *ogi* – a traditional food. This will not only contribute to enhancing food security but also help in minimizing nutritional deficiencies in the populace. This study is therefore aimed at evaluating the functional and antioxidative properties of sorghum flour enriched with cocoa powder at varying proportion.

MATERIALS AND METHODS

Materials

Sorghum grains (*Sorghum bicolor* L. Moench) were obtained from the Training and Research farm of Obafemi Awolowo University, Ile-Ife, Nigeria. Cocoa powder was procured from Cocoa Products (Ile-Oluji) Limited, Ondo

State. Chemicals used were of analytical grade and were procured from Sigma Aldrich (St. Louis, MO).

Production of sorghum *ogi*

Sorghum bicolor L. Moench grains were sorted, cleaned and washed under tap water to remove extraneous materials. The washed grains (2 kg) were steeped in tap water (5 L) for a period of 48 h at 28 ± 2 °C in a covered plastic bucket. The steep water was decanted, and the fermented grains were washed and later wet milled. The resulting paste was sieved using muslin cloth. The filtrate was allowed to settle and ferment for 24 h to heighten partial solidification of the sorghum *ogi* paste. The paste was dried in a cabinet dryer at 60 °C for 24 h to obtain the powdery form of sorghum *ogi*. The cooled dried samples were dry milled, packaged in thick polythene bags and labelled appropriately (Ajanaku *et al*., 2012).

Production of sorghum-cocoa *ogi* samples

Sorghum-cocoa *ogi* samples were produced by blending cocoa powder and *ogi* powder with a blender (SAISHO Magic Blender S-742, China). The cocoa powder was added in proportional gradients of 0, 10, 20, 30, 40 and 50% to sorghum *ogi* powder.

Physicochemical analyses

The pH and total titratable acidity (TTA) were determined using the methods of AOAC (2010) on 10% (w/v) suspension. The TTA was expressed as % lactic acid.

Functional properties

Determination of bulk density

A 10 mL graduated cylinder was gently filled with the sample. The bottom of the cylinder was tapped on a laboratory bench for 50 times until there is no further diminution of the sample level after filling to the 10 mL mark. Bulk density was calculated as the weight of sample per unit volume of sample (Siddique *et al*., 2010).

Determination of least gelation concentration (LGC)

Sample suspensions of 2 to 20% (w/v) were prepared in 5 mL distilled water in test tubes. The tubes containing the suspensions were then heated for 1 h in a boiling water bath. The tubes, after heating, were cooled rapidly in water at 4 °C for 2 h. Each tube was then inverted. The concentration at which the sample from the inverted test tube did not slip was taken as the LGC (Sathe and Salunkhe, 1981).

Determination of swelling power and solubility

Swelling power and solubility were determined using the method described by Takashi and Sieb (1988) with slight modifications. It involves weighing 1 g of the sample into 50 mL centrifuge tube; 10 mL of distilled water was added and mixed gently. The slurry was heated in a water bath at temperatures of 60, 70, 80 and 90 °C for 30 min. On completion of 30 min, the tube containing the paste is centrifuged (0502-1 Hospibrand, USA) at 3500 × g for 20 min. The supernatant was decanted immediately after centrifuging. The weight of the sediment was recorded. The moisture content of the sediment gel was used to determine the dry matter content of the gel. The parameters were used to calculate the swelling capacity. For solubility, the earlier decanted supernatant was poured into crucibles and dried in the oven at 120 °C until the supernatant was dried off. The residue remaining in the tubes were weighed and the crucible after drying with the supernatant.

$$\text{Swelling capacity (\%)} = \frac{\text{Weight of wet mass sediment}}{\text{Weight of dry matter in gel}} \times 100$$

$$\text{Solubility (\%)} = \frac{\text{Dry weight at } 120\ ^{\circ}\text{C}}{\text{Sample weight}} \times 100$$

Determination of water absorption capacity

A sample of 1 g was mixed in 10 mL of distilled water in a centrifuge tube. The centrifuge tube containing the suspension was weighed after mixing. The mixture was allowed to stand for 10 min and centrifuged at 4000 rpm for 15 min. The supernatant was decanted and the centrifuge tube weighed. This test was conducted at room temperature, 60, 70, 80 and 90 °C (Malomo *et al*., 2012).

Determination of oil absorption capacity

Oil absorption capacity (OAC) of each of the samples was determined by the method illustrated by Appiah *et al*. (2011) with slight modifications. A sample of 1 g was weighed into a previously weighed centrifuge tube (40

mL in volume) and 10 mL of pure Gino® oil was added into the sample in tube. The sample was mixed with 10 mL of pure Gino® oil for 60 s. The mixture was allowed to stand for 10 min at room temperature, centrifuged at 2000 × g for 30 min using a centrifuge (0502-1 Hospibrand, USA). The oil phase was carefully decanted and the tube was allowed to drain at a 45° angle for 10 min and then weighed. OAC was expressed as percentage of the volume of oil absorbed by the sample.

Antioxidant assay

Determination of DPPH radical scavenging ability

The free radical scavenging ability using α, α-diphenyl-β-picrylhydrazyl (DPPH) was determined as described by Pownall *et al*. (2010). Different concentrations of 1 mL of the aqueous extracts of each of the samples were added to 1 mL of 0.3mM DPPH dissolved in methanol in different test tubes. The tubes were shaken vigorously and allowed to stand in the dark for 30 min at room temperature. A control without the sample was prepared as above. The changes in absorbance of the samples were measured at 517 nm using a UV-VIS spectrophotometer (Model SP9, PyeUnican, UK). Free radical scavenging ability was expressed as 50% maximal radical inhibition concentration (DPPH IC_{50}).

Determination of metal chelating (MC) ability

The assay was carried out according to the method of Singh and Rajini (2004) with some modifications. Solutions of 2 mM $FeCl_2.4H_2O$ and 5 mM ferrozine were separately diluted 20 times. Briefly, an aliquot of 1 mL of the different concentrations (0.5, 1.0, 1.5, 2.0 and 2.5 µg/mL) of each sample was mixed with 1 mL of diluted $FeCl_2.4H_2O$. After 5 min incubation, the reaction was initiated by the addition of 1 mL of diluted ferrozine. The mixture was shaken vigorously and after a further 10 min incubation period, the absorbance of the solution was measured at 562 nm. The 50% maximal inhibition concentration (MC IC_{50}) of the samples were recorded.

Determination of ferric reducing antioxidant power (FRAP)

Acetate buffer of pH 3.6 (300 mmol/L), 10 mmol/L of 2, 4, 6-tri-(2-pyridyl)-1, 3, 5-triazine and 20 mmol/L of $FeCl_3.6H_2O$ were mixed together in the ratio of 10:1:1 respectively, to give the working FRAP reagent. A 50 µL aliquot of each sample at 1 mg/mL and 50 µL of standard solutions of ascorbic acid (20, 40, 60, 80, 100 µg/mL) were separately added to 1 mL of FRAP reagent. The mixture was well mixed and absorbance measured at 593 nm against reagent blank (50 µL of distilled water and 1 mL of FRAP reagent) after allowing reaction to complete at exactly 10 min (Benzie and Strain, 1999). Results were expressed in milligrammes ascorbic acid equivalent per gramme (mg AAE/g) of methanolic extracts of the samples.

Determination of total phenolic content (TPC)

The TPC of the extracts of the samples was determined using the Folin-Ciocalteu method as described by Gulcin *et al*. (2003). The methanolic extract (0.1 mL) dissolved in 0.9 mL of distilled water was reacted with 0.2 mL Folin-Ciocalteu's phenol reagent in the presence of 1 mL of 7% (w/v) sodium carbonate solution for 2 h at ambient temperature. The absorbance was measured at 750 nm using a UV-VIS spectrophotometer (Model SP9, PyeUnican, UK). Gallic acid was used as a standard and the results were expressed as gallic acid equivalents.

Statistical analysis

The statistical significance of the differences among the means of triplicate readings of results obtained were evaluated using analysis of variance. Means were separated using Duncan's multiple range test at 95% confidence level.

RESULTS AND DISCUSSION

PHYSICOCHEMICAL PROPERTIES

pH

pH values of all the sorghum *ogi* samples are presented in Table 1. The values ranged from

4.13 to 6.69. The trend was similar to the trend (4.11 to 6.18) reported by Ajanaku *et al*. (2012) for groundnut fortified sorghum *ogi* samples. The 100% sorghum *ogi* had a pH value of 4.13. The acidic pH was expected because fermented cereal products such as *ogi* usually have high acidity (Molin, 2008). This is often associated to the actions of acid-producing microorganisms like the lactic acid bacteria during the fermentation process (Molin, 2008). The incorporation of cocoa powder considerably increased the pH value in succession as the enrichment levels increased. This was attributed to the degree of the acidity of the cocoa powder used. This pH value (6.98) tended towards neutral because of the alkalisation process during the production of cocoa powder (Dyer, 2003). The pH values of all the samples were still at the acidic range though enrichment reduced the degree of acidity, it would however pose no disadvantage to the storability of the product because of the low moisture content of the samples.

Total titratable acidity

The TTA in percent lactic acid of the sorghum *ogi* samples as influenced by enrichment with cocoa powder is shown in Table 1. The values ranged between 0.109 and 0.198% lactic acid. The TTA values decreased significantly ($p<0.05$) as the level of enrichment with cocoa powder increased. This could be attributed to the low titratable acidity (0.025% lactic acid) of the cocoa powder as compared to the 100% sorghum *ogi*. The TTA of the control sample (0.198% lactic acid) was approximately similar to 0.218% lactic acid reported by Wakil and Ajayi (2013) for sorghum *ogi*. The sample enriched with 50% cocoa powder had the lowest among the enriched sorghum *ogi* samples owing to the influence of cocoa powder which had been nearly neutralised during the alkalisation process of cocoa powder production. The cocoa powder used had a TTA of 0.025% (Table 1) which was similar to 0.029% lactic acid reported by Olugbuyiro *et al*. (2011) for cocoa powder. The reduction of acidity observed for the enriched samples could be an advantage to ulcerative patients and people with stomach disorders.

FUNCTIONAL PROPERTIES

Bulk density

The bulk densities of the samples are presented in Table 1. The bulk densities ranged between 0.646 and 0.515 g/mL. The control sample had the highest bulk density (0.646 g/mL) when compared to the enriched samples. Since substitution is by weight, it means that the weight of cocoa was used to replace sorghum flour. This then means the volume of cocoa powder is higher than the volume of sorghum powder of same weight and hence the reduced bulk density. The observed decrease in the bulk density of the enriched sorghum *ogi* samples as the level of enrichment increased was also reported by Ajanaku *et al*. (2012) for sorghum *ogi* fortified with groundnut. They reported values in the range of 0.728 to 0.413g/mL as groundnut addition increased. The variation in bulk density had been reported to be influenced by the quantity of starch and most importantly, by the structure of starch polymers. Loose structure of starch polymers could also result in low bulk density (Malomo *et al*., 2012). The lower bulk densities of all the enriched samples as compared against the control sample therefore suggest their possible use as infant food formulation.

Oil absorption capacity

The OAC of all the samples varied significantly ($p<0.05$) between 133.50 and 144.24% as presented in Table 1. The highest value of OAC was observed for the sample containing 50% cocoa powder (144.24%) while the lowest value was obtained for the control sample. OAC of the samples increased as the enrichment levels increased. This was in agreement with the observations of Adetuyi and Adelabu (2011) for plantain flour enriched with okra seed flour and Fasasi *et al*. (2007) for maize *ogi* flour fortified with fermented Nile tilapia flour. The increase could be attributed to intrinsic factors like protein conformation and hydrophobicity or surface polarity (Chandra and Samsher, 2013).

Table 1. Physicochemical properties of samples

Sample	pH	TTA (% lactic acid)	BD (g/mL)	OAC (%)	LGC (%)
A	4.13 ± 0.01^{g}	0.198 ± 0.004^{a}	0.646 ± 0.005^{a}	133.50 ± 0.02^{g}	6^{a}
B	5.72 ± 0.01^{f}	0.185 ± 0.002^{b}	0.557 ± 0.007^{b}	135.68 ± 0.03^{f}	8^{b}
C	6.11 ± 0.01^{e}	0.167 ± 0.001^{c}	0.544 ± 0.003^{c}	136.90 ± 0.02^{e}	8^{b}
D	6.43 ± 0.01^{d}	0.144 ± 0.003^{d}	0.516 ± 0.000^{d}	138.10 ± 0.02^{d}	10^{c}
E	6.60 ± 0.01^{c}	0.131 ± 0.002^{e}	0.515 ± 0.000^{d}	141.32 ± 0.01^{c}	10^{c}
F	6.69 ± 0.02^{b}	0.109 ± 0.005^{f}	0.515 ± 0.000^{d}	144.24 ± 0.04^{b}	12^{d}
G	6.98 ± 0.01^{a}	0.025±0.003^{g}	0.394 ± 0.001^{e}	148.97 ± 0.02^{a}	12^{d}

The mean values along the same column with different superscripts are significantly different ($p< 0.05$)
A - 100% Sorghum *ogi;* B - Sorghum *ogi* enriched with 10% cocoa powder; C - Sorghum *ogi* enriched with 20% cocoa powder; *D* - Sorghum *ogi* enriched with 30% cocoa powder; E - Sorghum *ogi* enriched with 40% cocoa powder; F - Sorghum *ogi* enriched with 50% cocoa powder; G - 100% Cocoa powder

The sample containing 50% cocoa powder could therefore retain flavour better than other samples because fat improves flavour retention which is evidenced by its high OAC. The ability of all the sorghum *ogi* samples to bind with oil would probably make them useful in foods where prime oil absorption is preferred (Chandra and Samsher, 2013).

Least gelation concentration

The results of the LGC of all the samples are presented in Table 1. The values ranged between 6 and 12%. The control sample had the lowest value (6%) of LGC which was lower than 10% reported for maize *ogi* by Fasasi *et al*. (2007). It was however comparable to 6% reported by Onweluzo and Nwabugwu (2009) for 48 h fermented millet flour. Sorghum *ogi* sample enriched with 50% cocoa powder exhibited the highest value (12%) of LGC. The samples enriched with 10 and 20% cocoa powder exhibited gelation concentration at 8% which was comparable to 8% reported for 48 h fermented pigeon pea flour by Onweluzo and Nwabugwu (2009). Samples enriched with 30 and 40% cocoa powder had LGC of 10%. It was observed that the enrichment of sorghum *ogi* with cocoa powder increased the gelation concentration of sorghum *ogi*. This indicates that more samples will be required in same water content for gelatinization to occur in the cocoa enriched samples. Since enrichment with cocoa powder increased the flour concentration required for gel formation, all the enriched samples could be used in infant formulation to enhance nutrient density (Ezeji and Ojmelukwe, 1993).

Swelling power and solubility

The results of swelling power and solubility of sorghum *ogi* samples at different temperatures are presented in Figures 1 and 2, respectively.

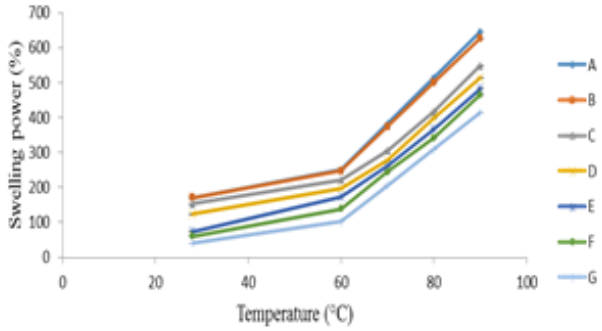

Fig. 1. Effect of temperature on swelling power: A - 100% Sorghum *ogi;* B - Sorghum *ogi* enriched with 10% cocoa powder; C - Sorghum *ogi* enriched with 20% cocoa powder; *D* - Sorghum *ogi* enriched with 30% cocoa powder; E - Sorghum *ogi* enriched with 40% cocoa powder; F - Sorghum *ogi* enriched with 50% cocoa powder; G - 100% Cocoa powder

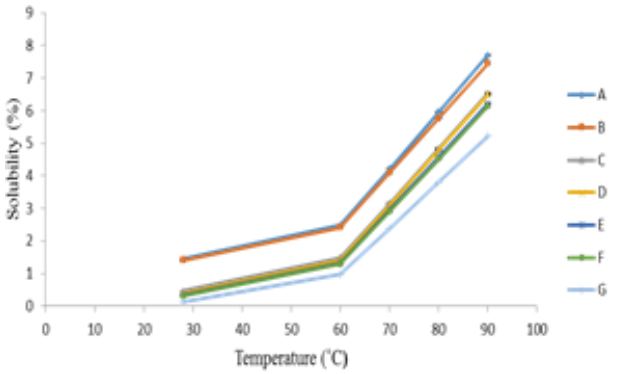

Fig. 2. Effect of temperature on solubility: A - 100% Sorghum *ogi;* B - Sorghum *ogi* enriched with 10% cocoa powder; C - Sorghum *ogi* enriched with 20% cocoa powder; *D* - Sorghum *ogi* enriched with 30% cocoa powder; E - Sorghum *ogi* enriched with 40% cocoa powder; F - Sorghum *ogi* enriched with 50% cocoa powder; G - 100% Cocoa powder

The swelling power of all the evaluated samples increased with increase in temperature. The increase in swelling power as temperature increased was similar to the observation of Akinyele *et al*. (2015) for *pupuru* and *pupuru* analogues. Sorghum *ogi* had the highest swelling power among all the samples evaluated at the temperatures used for evaluation. There were significant increases ($p<0.05$) in the swelling power of all the evaluated sorghum *ogi* samples at temperatures 60, 70, 80 and 90 ˚C which might be as a result of the increase in temperature which tends towards starch gelatinization temperature. It was notably observed that the incorporation of cocoa powder having a swelling power of 414% (Figure 1) into sorghum *ogi* resulted in decrease in the swelling power of the enriched samples. This implies that the hydrophilic tendency of the samples (Aviara *et al*., 2010) decreased with increase in enrichment level. Decrease in swelling power was also observed by Abioye and Aka (2015) for moringa fortified maize *ogi*. This decrease might also be as a result of the presence of naturally occurring non-carbohydrates such as lipids contributed largely by the cocoa powder which could restrict swelling. This restriction occurs when amylase lipid complexes are formed (Olayinka *et al*., 2008).

On the other hand, increase in solubility was noticed in all the sorghum *ogi* samples as temperature increased. The solubility of the samples is presented on Figure 2. Solubility was highest in the control sample. Enrichment of sorghum *ogi* with cocoa powder significantly reduced ($p<0.05$) the degree of solubility of the enriched samples. This could be attributed to the nature and quantity of components, most especially the cellulosic fraction (having β (1-4) ordered linkages which are insoluble) of the dietary fibre. Amylose content and the lipophilic molecules in the cocoa powder may also interfere with the hydrophilic tendencies of the enriched samples (Oakenfull, 2001; Sodhi and Singh, 2003).

The mathematical relationships existing between the swelling power and temperature as well as solubility and temperature for each sample were found to be polynomial of the second order which is presented in Tables 2 and 3. This was because the R-squared (r^2) values of this regression equation was found to be the highest (much closer to unity) when compared to other regression relationships such as linear, exponential, logarithmic and power.

The order of relationship reported in this study, was also observed by Aviara *et al*. (2010) for sorghum starch and Fasasi *et al*. (2007) for maize-tilapia flour blends. The relationships which could be used for predictability of swelling power and solubility of the samples at any temperature within the range of 28 and 90 ˚C showed that the solubility and swelling power of sorghum *ogi* increased with increase in temperature but decreased with proportionate addition of cocoa powder.

Table 2. Mathematical relationship for swelling power at different temperatures

Sample	Polynomial Regression equation	R^2	R_1^2	R_2^2	R_3^2	R_4^2
A	$Y = 0.16T^2 - 10.56T + 340.75$	0.9931	0.8598	0.9569	0.7362	0.8844
B	$Y = 0.15T^2 - 10.12T + 333.85$	0.9931	0.8603	0.9572	0.7369	0.8848
C	$Y = 0.14T^2 - 10.14T + 327.04$	0.9998	0.8600	0.9844	0.7364	0.9473
D	$Y = 0.13T^2 - 9.07T + 273.49$	0.9980	0.8605	0.9868	0.7370	0.9574
E	$Y = 0.11T^2 - 6.65T + 171.17$	0.9992	0.8603	0.9872	0.7369	0.9591
F	$Y = 0.12T^2 - 8.08T + 186.49$	0.9965	0.8603	0.9879	0.7368	0.9634
G	$Y = 0.12T^2 - 8.31T + 173.41$	0.9931	0.8603	0.9857	0.7368	0.9861

A - 100% Sorghum *ogi;* B - Sorghum *ogi* enriched with 10% cocoa powder; C - Sorghum *ogi* enriched with 20% cocoa powder; *D* - Sorghum *ogi* enriched with 30% cocoa powder; E - Sorghum *ogi* enriched with 40% cocoa powder; F - Sorghum *ogi* enriched with 50% cocoa powder; G - 100% Cocoa powder

R^2- Polynomial R^2; R_1^2 - Linear R^2; R_2^2 - Exponential R^2; R_3^2 - Logarithmic R^2; R_4^2 - Power R^2

Table 3. Mathematical relationship for solubility at different temperatures

Sample	Polynomial Regression equation	R^2	R_1^2	R_2^2	R_3^2	R_4^2
A	$Y = 0.0021T^2 - 0.1395T + 3.6865$	0.9930	0.8598	0.9569	0.7362	0.8844
B	$Y = 0.002T^2 - 0.1343T + 3.5599$	0.9931	0.8603	0.9572	0.7369	0.8848
C	$Y = 0.002T^2 - 0.1349T + 2.6432$	0.9932	0.8600	0.9844	0.7364	0.9473
D	$Y = 0.002T^2 - 0.1354T + 2.5583$	0.9931	0.8605	0.9868	0.7370	0.9574
E	$Y = 0.0019T^2 - 0.1303T + 2.4455$	0.9931	0.8603	0.9872	0.7369	0.9591
F	$Y = 0.0019T^2 - 0.1292T + 2.3884$	0.9931	0.8603	0.9879	0.7368	0.9634
G	$Y = 0.0017T^2 - 0.1132T + 1.9409$	0.9931	0.8603	0.9857	0.7368	0.9861

A - 100% Sorghum *ogi;* B - Sorghum *ogi* enriched with 10% cocoa powder; C - Sorghum *ogi* enriched with 20% cocoa powder; *D* - Sorghum *ogi* enriched with 30% cocoa powder; E - Sorghum *ogi* enriched with 40% cocoa powder; F - Sorghum *ogi* enriched with 50% cocoa powder; G - 100% Cocoa powder

R^2- Polynomial R^2; R_1^2 - Linear R^2; R_2^2 - Exponential R^2; R_3^2 - Logarithmic R^2; R_4^2 - Power R^2

Water absorption capacity

Water absorption capacities of all the samples as affected by varying temperatures are presented in Figure 3.

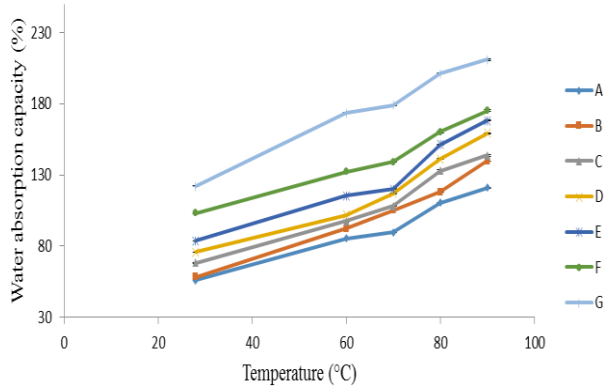

Fig. 3. Effect of temperature on water absorption capacity

A - 100% Sorghum *ogi;* B - Sorghum *ogi* enriched with 10% cocoa powder; C - Sorghum *ogi* enriched with 20% cocoa powder; *D* - Sorghum *ogi* enriched with 30% cocoa powder; E - Sorghum *ogi* enriched with 40% cocoa powder; F - Sorghum *ogi* enriched with 50% cocoa powder; G - 100% Cocoa powder

There were significant differences ($p<0.05$) in the water absorption capacity of the samples as temperature increased. The water absorption of the samples showed an increase as cocoa powder addition increased.

Sample with 50% cocoa powder had the highest WAC while the control sample had the lowest. The observed increase in WAC of the enriched samples could be attributed to the higher WAC of cocoa powder. Cocoa powder has been reported to have higher water absorption capacity (100% of its own weight) than flour which absorbed not more than 60% of its own weight (ADM Cocoa, 2009). High water absorption of cocoa powder had been linked to the hygroscopicity, low water activity, and high dietary fibre of cocoa powder when compared to that of the control sample (ADM Cocoa, 2009).

Increase in WAC was reported by Olapade *et al.* (2012) for instant cowpea powder and Apotiola (2013) for sorghum *ogi.* Fasasi *et al.* (2007) also reported that the addition of fermented tilapia to maize *ogi* increased water absorption capacity. Sefa-Dedeh *et al.* (2001) similarly reported that water absorption capacity in maize *ogi* increased with the addition of cowpea. The relatively high water absorption capacity of the sorghum *ogi* as well as the enriched samples is an advantage because of its positive effect on food consistency and their potentiality of usage as thickeners in liquid and semi-liquid foods. This is because water absorption capacity is one of the important parameters that is usually considered when incorporating food powders in aqueous food formulations (Iwe and Onadipe, 2001) especially those involving dough handling. As presented in Table 4, the relationship describing water absorption capacity and temperatures for each sample was largely polynomial in nature. This relationship showed that WAC of the sorghum *ogi* samples increased with increase in temperature. This agreed with the relationship described by Fasasi *et al.* (2007) for the WAC of maize-tilapia flour blends.

Table 4. Mathematical relationship for water absorption capacity at different temperatures

Sample	Polynomial Regression equation	R^2	R_1^2	R_2^2	R_3^2	R_4^2
A	$Y = 0.0074T^2 + 0.1800T + 45.346$	0.9849	0.9673	0.9881	0.9050	0.9611
B	$Y = 0.009T^2 + 0.2214T + 45.097$	0.9969	0.9792	0.9985	0.9167	0.9768
C	$Y = 0.0112T^2 - 0.0569T + 60.641$	0.9878	0.9598	0.9883	0.8855	0.9465
D	$Y = 0.0177T^2 - 0.7104T + 81.522$	0.9963	0.9374	0.9784	0.8429	0.9136
E	$Y = 0.0170T^2 - 0.6285T + 88.085$	0.9793	0.9258	0.9669	0.8373	0.9074
F	$Y = 0.0110T^2 - 0.1378T + 98.396$	0.9922	0.9600	0.9843	0.8843	0.9323
G	$Y = -0.0022T^2 + 1.6960T + 76.421$	0.9893	0.9885	0.9802	0.9741	0.9898

A - 100% Sorghum *ogi;* B - Sorghum *ogi* enriched with 10% cocoa powder; C - Sorghum *ogi* enriched with 20% cocoa powder; *D* - Sorghum *ogi* enriched with 30% cocoa powder; E - Sorghum *ogi* enriched with 40% cocoa powder; F - Sorghum *ogi* enriched with 50% cocoa powder; G - 100% Cocoa powder

R^2- Polynomial R^2; R_1^2 - Linear R^2; R_2^2 - Exponential R^2; R_3^2 - Logarithmic R^2; R_4^2 - Power R^2

ANTIOXIDATIVE ACTIVITIES

Dpph radical scavenging, metal chelating and FRAP activities

The DPPH IC_{50} and MC IC_{50} of the samples are presented in Table 5. Sorghum *ogi* sample enriched with 50% cocoa powder had the lowest DPPH IC_{50} (0.752 mg/mL) and MC IC_{50} values (0.082 mg/mL). The control sample recorded the highest. This implies that the sample with the highest enrichment level would require the least amount of sample to chelate metals and to scavenge 50% of DPPH radical. This also indicates that the antioxidant potency of the sorghum *ogi* samples increased with the addition of cocoa powder which is expected because cocoa powder has relatively high antioxidant activities (Jalil and Ismail, 2008). From the results presented, none of the samples was as potent as the standards (ascorbic acid and EDTA) in scavenging radicals and chelating metals. However, all the sorghum *ogi* samples, most especially, the enriched samples are relatively good sources of antioxidants.

As presented in Table 5, the FRAP of the samples ranged between 0.0025 and 0.0502 mg AAE/g. This depicted an increase of 20-fold for 50% cocoa powder enriched sorghum *ogi*. The control sample had the lowest ferric reducing antioxidant activity (0.0025 mg AAE/g). This indicates that cocoa powder contributed significantly to the ferric reducing antioxidant power of the enriched samples.

Total phenolic content

The total phenolic contents of all the samples are presented in Table 5. The values ranged between 7.76 and 15.21 mg GAE/g which showed an increase of 19.24 to 96.00% for 10 to 50% cocoa powder inclusion. This depicts that the addition of cocoa powder increased the polyphenols of the samples. Sorghum *ogi* with 50% cocoa powder had the highest TPC.

Table 5. Antioxidant properties of samples

Sample	DPPH IC_{50} (mg/mL)	MC IC_{50} (mg/mL)	FRAP(mg AAE /g)	TPC (mg GAE /g)
A	1.789 ± 0.002^{a}	0.126 ± 0.001^{a}	0.0025 ± 0.001^{g}	7.760 ± 0.012^{g}
B	1.531 ± 0.003^{b}	0.118 ± 0.002^{b}	0.0124 ± 0.001^{f}	9.253 ± 0.011^{f}
C	1.375 ± 0.001^{c}	0.106 ± 0.001^{c}	0.0214 ± 0.001^{e}	10.731 ± 0.002^{e}
D	1.115 ± 0.002^{d}	0.098 ± 0.002^{d}	0.0312 ± 0.001^{d}	12.261 ± 0.001^{d}
E	0.908 ± 0.004^{e}	0.091 ± 0.002^{e}	0.0406 ± 0.002^{c}	13.664 ± 0.002^{c}
F	0.752 ± 0.001^{f}	0.082 ± 0.001^{f}	0.0502 ± 0.001^{b}	15.210 ± 0.001^{b}
G	0.441 ± 0.003^{g}	0.059 ± 0.001^{g}	0.0983 ± 0.001^{a}	22.787 ± 0.003^{a}
Ascorbic acid	0.101 ± 0.001^{h}	-	-	-
EDTA	-	0.044 ± 0.002^{h}	-	-

Values are means of triplicate determinations ± standard deviation

The mean values along the same row with different superscripts are significantly different ($p < 0.05$)

A - 100% Sorghum *ogi;* B - Sorghum *ogi* enriched with 10% cocoa powder; C - Sorghum *ogi* enriched with 20% cocoa powder; *D* - Sorghum *ogi* enriched with 30% cocoa powder; E - Sorghum *ogi* enriched with 40% cocoa powder; F - Sorghum *ogi* enriched with 50% cocoa powder; G - 100% Cocoa powder

This was expected because cocoa powder had been known to contain higher amount of polyphenols in the range of 18.62 and 63.20 mg GAE/g (Miller *et al*., 2008) as against that of sorghum grain which ranged between 2.33 and 7.87 mg GAE/g (Mohamed *et al*., 2009). The high amount of phenolic content in the sorghum *ogi* samples, especially the enriched samples, may be a function of their high antioxidant activities. This may help in the prevention of various diseases associated with oxidative stress (Atmani *et al*., 2009).

CONCLUSION

This study established the effects of the addition of cocoa powder to sorghum *ogi* on the functional and anti-oxidative properties of the products. The low bulk density of the blends indicates the suitability of the blends in the preparation of high nutrient density complementary/supplementary food. The effects of the inclusion of cocoa powder on the swelling and solubility behaviour of the products as well as their respective relationships with varying temperatures were established. The boosting of the antioxidants in the samples through enrichment could help in the prevention of oxidative stresses which had been largely implicated in the development of abnormal cells and ageing. The sorghum-cocoa blends could be useful where health promoting gruels from sorghum are desirable such as in the production of weaning foods.

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