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Predicting the Digestibility of Nutrients and Energy Values of 4 Breadfruit Varieties Based on Chemical Analysis

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Abstract: Different breadfruit varieties were analyzed to determine their chemical composition using standard procedures. The results were used to establish prediction equations of DDM, DMI, NEL and RFV. No significant differences were found in the tannin contents which ranged between 3.44 mg/100 g to 4.30 mg/100 g. Lignin content was highest in *A. camansi* (12.1%) compared to the least (3.54%; *T. africana*). *T. africana* had the highest DDM (78.51%) whereas *A. camansi* had the least (70.21%). DMI was highest in *A. altilis* (2.65% per body weight) and lowest in *T. africana* (1.72%/kg body weight). *T. africana* having the highest NEL (88.00 Mca/lb) was similar to *A. heterophyllus* (86.77 Mcal/lb) but higher than *A. camansi*. *A. altilis* had higher RFV (156.48) compared to *A. camansi* (137.13), *A. heterophyllus* (126.18) and *T. africana* (104.88). The breadfruit varieties have good chemical composition and digestibility and therefore vindicate their use as food and feed. The predictors for DDM were ADL, lignin, hemicelluloses and NDF. DDI was dependent on carbohydrate, fat ADF, hemicelluloses and NDF contents. On the other hand NEL was predictable from ADL, lignin and hemicelluloses while RFV was dependent on the carbohydrate, fat and NDF content. Predictive equations derived in this study could be used in estimating nutrient digestibility and energy if relevant chemical composition is known without doing expensive feeding trials.

Key words: Digestibility, energy value, prediction, chemical composition

INTRODUCTION

Breadfruits belonging to the family Moracea (Ragone, 2006a,b) have been used as food as well as feed in many parts of the tropics including the Pacific and West Africa (Orwa *et al.*, 2009; Taylor and Tuia, 2007; Gamedoagbao and Bennett-Lartey, 2007). Important varieties include *Artocarpus altilis* (Breadfruit), *Artocarpus camansi* (Breadnut), *Artocarpus heterophyllus* (Jackfruit), *Treculia africana* (African breadfruit). Breadfruits have been reported to be good sources of energy and minerals for both human food and animal feed (Appiah *et al.*, 2011; Orwa *et al.*, 2009; Ragone 2006a, 2006b; Morton, 1987; Irvine 1961). To promote its use as food or feed it is important to establish the relationships among chemical constituents and digestibility of breadfruits. Although of work has been done on the nutritional composition as well as the functional properties of breadfruits, little scientific information has been reported regarding the relationships existing between their chemical constituents, energy and digestibility indicators. However, it is important for food as well as feed formulators to be able to predict energy and digestibility of the breadfruits using their chemical composition. This will reduce the cost of production as it will help to minimize expensive feeding trials of feed formulated with breadfruits. The aim of this study therefore, was to determine the relationships that exist between the chemical composition, energy and nutrient digestibility of breadfruits to enable prediction of digestibility and energy.

MATERIALS AND METHODS

Sample preparation: Fresh fruits of *Artocarpus altilis* (Breadfruit), *Artocarpus camansi* (Breadnut), *Artocarpus heterophyllus* (Jackfruit), *Treculia africana* (African breadfruit). *Artocarpus altillis* fruits were harvested from the Botanical garden of the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. *A.altilis* fruits were peeled and the pulp sliced into 2 cm^3 chunks while *A. heterophyllus* and *A. camansi* and *T. africana* nuts were extracted by hand. They were then dried in an oven at 60°C for 48 h, milled and sieved with 75 µm mesh. The flours were kept in a refrigerator prior to analysis.

Chemical analysis: Samples were analysed for contents of crude fibre, crude protein, crude fat, ash, Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF) and Acid Detergent Lignin (ADL). Crude fat was extracted with petroleum ether whereas the Kjeldahl method was used to determine nitrogen (AOAC, 1990). Crude protein was then calculated as N x 6.25. NDF, ADF and ADL were determined according to the methods of Van Soest

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and Wine (1967). Hemicellulose was calculated as NDF-ADF and cellulose as ADF-ADL (Rinne *et al.*, 1997). Cell solubles were determined as 100-NDF (Belyea and Ricketts, 1993). Lignin was estimated as ADL-Mineral Ash (Richards *et al.*, 2005). Tannin content was estimated using the modified vanillin hydrochloride in methanol method described by Price *et al.* (1978). Net Energy for Lactation (NEL) was estimated as 1.044-0.0123*ADF as recommended by Cooperative Resources International (2006). Digestible Dry Matter (DDM), Dry Matter Intake (DMI) and Relative Feed Value (RFV) were estimated as 88.9-0.779*ADF, 120/NDF and DDM*DMI/1.29 respectively as suggested by Schroeder (1994). NDF, ADF, ADL, hemicelluloses, cellulose and DDM were expressed as percentages (1 to 100) , DMI as percent body weight, while NEL were expressed as Mcal/lb. Tannin was reported in mg/100 g.

Statistical analysis: Statistix9 statistical software was used to compute Analysis of Variance (ANOVA) while least significant difference test was used to determine differences between means. Correlation and regression analysis were carried out on the data to determine relationships between parameters. All data were reported as mean±SD.

RESULTS AND DISCUSSION

Chemical composition: The results of the chemical analysis are presented in Table 1. The crude protein content of the *A. camansi* (17.72 g/100 g), *T. africana* (17.57 g/100 g) and *A. heterophyllus* (12.23 g/100 g) were higher than in *A. altilis* (3.8 g/100 g). The results show that consuming 300 g of *A. camansi*, *T. africana* and *A. heterophyllus* daily would provide the recommended daily of proteins of (34-56 g/day) for human adults and children (13-19 g/day) (Food and Nutrition Board, 2002). The carbohydrate content of the breadfruit varieties was comparable to maize (66.0-75.9%; Ortega *et al.*, 1986). The high carbohydrate content is indicative that the breadfruits could be good sources of energy (Appiah *et al.*, 2011) in foods.

The tannin content of the different breadfruit varieties were statistically similar and ranged between 3.44 and 4.30 mg/100 g. These were lower than the reported 13.3 g/100 g and 19.1 g/100 g for cashew nut and fluted pumpkin seeds respectively. Tannin has been reported to form complexes with proteins including enzymes resulting in reduced digestion and absorption (Osuntogun *et al.*, 1987). They are also known to bind Fe making it unavailable (Brune *et al.*, 1991) for absorption. In this study no significant correlation was observed between tannin content and DDM of the breadfruit flours (R = 0.13). Again, regression analysis did not identify tannin content as an important predictor of digestible dry matter (Table 4). The low tannin content and the high digestibility (DDM) indicates that the breadfruit varieties can be used as food or feed ingredients without much apprehension about digestibility as well as nutrient availability.

The Neutral Detergent Fibre (NDF) content of the different breadfruit flours varied significantly. *T. africana* had highest NDF content (69.67%; Table 2) which was 154% higher than the least (*A.altilis*; 45.33%). *A. altilis* and *A. camansi* had statistically similar (p>0.01) NDF content. According to Johnson and Marlett (1986) NDF represents the insoluble fraction of fiber which is primarily responsible for increasing stool weight, defeacation frequency and for decreasing gastrointestinal transit time. *T. africana* could therefore increase stool weight and reduce gastrointestinal transit and therefore reduce constipation more than the others.

The lignin content (Table 2), the major component of ADL (Richards *et al.*, 2005), was similar for *T. africana*, *A. altilis* and *A. heterophyllus* but statistically higher in *A. camansi*. Schroeder (1994) indicated that as lignin increases, digestibility, intake and animal performance usually decreases. It was therefore not surprising that *A. camansi* had the least Dry Matter Intake (DMI). According to Belyea and Ricketts (1993) lignin ties up cellulose indicating that higher concentrations of lignin results in reduced cellulose digestibility. The low Digestible Dry Matter (DDM) content (70.21%) of *A. camansi* could be attributed to its high lignin content. On the other hand, *T. africana* had the highest DDM (78.51%) suggesting that it was more digestible (Schroeder, 1994) than the rest. It is therefore not surprising that it is used in infant formulations particularly in Nigeria (Osuji and Owei, 2010; Amusa *et al.*, 2002).

The estimated net energy available for production and growth (NEL) was similar in *T. africana* (88.00 Mcal/lb), *A. heterophyllus* (86.77 Mcal/lb) and *A. altilis* (84.31 Mcal/lb). However, *A. camansi* (74.88 Mcal/lb), having the least NEL, differed significantly from the rest. Generally, breadfruit varieties had high NEL values suggesting they would be useful in providing sufficient energy for growth if consumed.

Table 1: Chemical composition of breadfruit flours

Variety	Crude protein (g/100 g)	Crude fat (g/100 g)	Ash (g/100 g)	Carbohydrates (g/100 g)	Tannin (mg/100 g)
A. camansi	17.72±0.62	6.33±0.30	2.90±0.05	64.18±0.70	3.44±0.09
A. heterophyllus	12.23±0.12	5.57±0.08	2.13±0.02	70.15±0.78	3.50±0.02
A. altilis	03.80±0.61	2.36±0.05	2.37±0.05	79.24±0.59	4.30±0.15
T. africana	17.57±0.45	9.08±0.14	2.64±0.02	57.00±0.33	3.59±0.02
LSD (0.01)	1.351	0.673	0.113	1.705	1.647

Table 2: Digestibility of nutrients of breadfruit flours

Variety	NDF (%)	ADF (%)	ADL (%)	Lignin (%)	HEM (%)	CELL (%)	CS (%)	DDM (%)	DMI (%)	NEL (Mcal/lb)	RFV
AC	47.67	24.00	15.00	12.10	23.67	5.67	52.333	70.21	2.51	74.88	137.13
	±1.53	±1.00	±1.00	±1.00	±0.58	±0.289	±1.53	±0.78	±0.08	±0.01	±5.95
AH	57.33	14.33	5.67	3.54	43.00	6.33	42.667	77.73	2.09	86.77	126.18
	±1.55	±0.16	±0.58	±0.58	±0.00	±0.58	±1.15	±0.90	±0.04	±0.01	±4.05
AA	45.33	16.33	6.67	4.32	29.00	9.67	54.667	76.18	2.65	84.31	156.48
	±1.53	±0.53	±0.56	±1.15	±0.00	±2.08	±1.53	±1.19	±0.09	±0.02	±7.64
TA	69.67	13.33	7.33	4.69	56.33	4.67	30.333	78.51	1.72	88.00	104.88
	±1.53	±0.58	±0.58	±0.58	±0.16	±0.58	±1.53	±0.45	±0.04	±0.01	±2.79
Lsd (0.01)	3.954	3.063	2.373	2.447	1.768	5.002	3.954	2.386	0.125	3.770	10.221

NDF - Neutral Detergent Fiber; ADF - Acid Detergent Fiber; ADL - Acid Detergent Lignin; HEM - Hemicellulose; CELLU - Cellulose; CS - Cell Soluble; DDM - Digestible Dry Matter; DMI - Dry Matter Intake; NEL - Net Energy for Lactation; RFV - Relative Feed Value

Table 3: Correlation coefficients between chemical characteristics and energy values of breadfruit flours

	CFAT	CFIB	NDF	ADL	LIG	CHO	CELLU	HEM	DDM	DMI	NEL	RFV	CPROT	TAN	ADF
CFAT	-														
CFIB	0.45	-													
NDF	0.75**	0.24	-												
ADL	-0.06	0.71*	-0.36	-											
LIG	-0.06	0.71*	-0.36	1.00**	-										
CHO	-0.80**	0.16	-0.76**	-0.30	-0.30	-									
CELLU	-0.39	0.39	-0.60*	-0.32	-0.33	0.73**	-								
HEM	0.68*	0.42	0.96**	-0.60*	-0.58	-0.56	-0.43	-							
DDM	0.33	0.70*	0.61*	-0.92**	-0.92**	-0.02	0.03	0.80**	-						
DMI	-0.68*	-0.17	-0.99**	0.36	0.36	0.73**	0.60*	-0.95**	-0.56*	-					
NEL	0.33	0.70*	0.61*	-0.92**	-0.92**	-0.02	0.03	0.80**	1.00**	-0.60*	-				
RFV	-0.68*	0.03	-0.95*	0.12	0.12	0.84**	0.70*	-0.84**	-0.36	0.96	-0.36	-			
CPROT	0.43	-0.58*	0.54	0.52	0.52	-0.89**	-0.78**	0.32	-0.25	-0.56	-0.25	-0.74**	-		
TAN	-0.19	0.64*	-0.52	-0.27	-0.27	0.67*	0.62*	-0.35	0.13	-0.57	0.13	0.71**	-0.87**	-	
ADF	-0.33	-0.70*	-0.61*	-0.92**	-0.92**	0.02	-0.03	-0.80**	-1.00**	0.60*	-1.00**	0.36	0.25	-0.13	-

CFAT - Crude Fat; CFIB- Crude Fiber; NDF - Neutral Detergent Fiber; ADL - Acid Detergent Lignin; LIG - Lignin; CHO - Carbohydrate; CELLU - Cellulose; HEM - Hemicellulose; DDM - Digestible Dry Matter; DMI - Dry Matter Intake; NEL - Net Energy for Lactation; RFV - Relative Feed Value; CPROT - Crude Protein; TAN - Tannin; ADF - Acid Detergent Fiber. *Significant at p = 0.05, **Significant at p = 0.01

All the varieties varied significantly from each other with respect to their estimated DMI. *A. altilis* (2.65%) had highest DMI, 1.5 times higher than the least (*T. africana*; 1.72%). The high DMI of *A. altilis* is attributable to the low NDF values as corroborated by the regression equation Y = 4.41 - 0.05ADF + 0.05FAT - 0.04Hemicellulose - 0.78 NDF (Equation 9) derived in this study. This observation is similar to that of Schroeder (1994) who indicted that as the percent NDF increases in feed mixes animals consume less.

As expected there was a significant correlation (R = -0.92) between lignin and DDM as well as NEL (R= -0.92) (Table 3). DDM was found to increase as hemicellulose content increased (R = 0.80). This could be attributable probably to higher digestibility of hemicellulose (Belyea and Ricketts, 1993) found in the breadfruits. The linear relationship DDM = 67.7 + 0.21Hemicellulose (Equation 2) give credence to the positive correlation found between DDM and hemicelluloses. Slavin *et al.* (1981) have reported that hemicelluloses is extensively degraded (71.7%) by humans on a low cellulose diet. Since the cellulose content of the breadfruit varieties was low it was expected that the hemicelluloses in the breadfruits would have high digestibility.

Dry matter intake was inversely related to NEL (R = -0.60) in line with the fact that intake of feed by animals is to satisfy energy requirements. More of low-energy feeds would be needed to meet the energy requirements of animals compared to high energy foods. DMI had a positive association (R = 0.73) with carbohydrate content as against an inverse relationship with NDF (R= -0.99). This was similar to the report of Schroeder (1994) who indicated that forages with high NDF values have less DMI values.

NEL was negatively correlated to lignin and ADL (R = -0.92). The results of this study show that hemicellulose was positively associated with NEL (R = 0.80) which was corroborated by the linear relationship NEL = 0.71 + 0.003 HEMICELLULOSE (Equation 11). Similar observations were made for NEL (equations 10-12). More accurate predictions of DDM were however made by predicting with lignin and hemicellulose combined (Equation 4) or hemicellulose and NDF combined (Equation 5). In the same vein NEL could be better predicted using both hemicelluloses and ADL or lignin.

The relative feed value is an index that combines the important nutritional factors of intake and digestibility. Relative Feed Value has been of great value in ranking forages for sale or inventorying and assigning forage to animal groups according to their quality needs (Moore, 2002). The Relative Feed Value (RFV) of the breadfruit varieties correlated positively with carbohydrate content

Table 4: Effect of chemical constituents on Digestible Dry Matter (DDM) for breadfruit flours

Equation No.	Relationship	R^2	P	RMSE
	Simple linear regression			
1	Y = 82.70 - 0.81 ADL	0.84	0.000	2.08
2	Y = 67.7 + 0.21 Hemicellulose	0.64	0.002	4.82
3	Y = 82.70 - 0.81 Lignin	0.84	0.000	2.09
	Multiple regression			
4	Y = 75.92 - 0.66 Lignin + 0.10 Hemicellulose	0.95	0.000	0.74

ADL - Acid Detergent Lignin

Table 5: Effect of chemical constituents on Dry Matter Intake (DMI) for breadfruit flours

Equation No.	Equation	R^2	P	RMSE
	Simple linear regression			
5	Y = -0.37 + 0.04 Carbohydrate	0.53	0.007	0.077
6	Y = 3.51 - 0.18 Fat	0.46	0.016	0.089
7	Y = 3.3 - 0.03 Hemicellulose	0.91	0.000	0.015
	Multiple regression			
8	Y = 0.87 - 0.07 Fat + 0.03 Carbohydrate	0.55	0.026	0.081
	Stepwise multiple regression			
9	Y = 4.41 - 0.05ADF + 0.05Fat - 0.04 Hemicellulose	1.00	0.000	$5.41*10^{-4}$

ADF - Acid Detergent Fiber; NDF - Neutral Detergent Fiber

Table 6: Effect of chemical constituents on Net Energy for Lactation (NEL) for breadfruit flours

Equation No.	Equation	R^2	P	RMSE
	Simple linear regression			
10	Y = 0.95 - 0.01 ADL	0.84	0.000	$5.19*10^{-4}$
11	Y = 0.71 + 0.003 Hemicellulose	0.64	0.001	0.0012
12	Y = 0.95 - 0.01 Lignin	0.84	0.000	$5.19*10^{-4}$

ADL - Acid Detergent Lignin

Table 7: Effect of chemical constituents on Relative Feed Value (RFV) for breadfruit flours

Equation No.	Equation	R^2	P	RMSE
	Simple linear regression			
13	Y = -26.58 + 2.37 Carbohydrate	0.71	0.001	127.55
14	Y = 197.30 - 9.68 Fat	0.46	0.015	236.55
	Multiple regression			
15	Y = 156.94 + 0.814Carbohydrate - 1.46NDF	0.94	0.000	28.259

NDF - Neutral Detergent Fiber

(R = 0.84) and cellulose content (R = 0.70) but negatively with NDF (R = -0.95), hemicellulose (R = -0.84) and crude fat content (R = -0.68). According to (Schroeder, 1994) as percent ADF and NDF decrease the RFV increases similar to what was observed in this study. *A. altilis* (156.48) had superior RFV than *A. camansi* (137.13), *A. heterophyllus* (126.18) and *T. africana* (104.88). According to Progressive Nutrition (2011) the higher the RFV in forages, the more digestible and palatable they are. This is because, as the non-digestible fiber (ADF and NDF) increases, the palatability is lowered and the rate of passage through the intestinal tract slows due to its poor fermenting quality. According to the reported grading by Progressive Nutrition (2011) *A. altilis* would therefore be a prime feed ingredient (RFV>151) while *A. camansi* and *A. heterophyllus* would be premium ingredients (RFV 125-150). On the other hand *T. africana* could be graded as good (RFV 103-124).

Although regression analysis showed that ADL (R^2 = 0.84), lignin (R^2 = 0.84) and hemicelluloses (R^2 = 0.64) were important single predictors of DDM (Table 4), lignin and hemicelluloses content together could predict DDM more accurately (R^2 = 0.95; Equation 4).

Dry matter intake was dependent on hemicelluloses, carbohydrate and fat contents of the flours (Table 5). Hemicellulose content was a better predictor (R^2=0.91) than carbohydrate (R^2 = 0.53) and fat content (R^2 = 0.46). However, a more accurate prediction of DMI was achieved by using ADF, Fat, Hemicellulose and NDF together (R^2 = 1.00; Equation 9).

NEL was found to be dependent on ADL, lignin and hemicelluloses content with R^2 values of 0.84, 0.84 and 0.64 respectively (Table 6). Lignin and ADL content were equally good predictors of NEL (Equation 10 and 12 respectively) and were better predictors than hemicelluloses (equation 11).

Table 7 shows the significant predictors of RFV. The RFV of the breadfruit varieties was dependent on carbohydrate content (R^2 = 0.71; equation 13) and fat content (R^2 = 0.46; equation 13). Multiple linear regression analysis revealed that using carbohydrate and NDF contents simultaneously resulted in prediction that was 94% accurate (R^2 = 0.94; equation 15).

Conclusion: This study provides equations for predicting accurately the digestibility coefficients of energy and nutrients in breadfruits. The digestibility and energy values of breadfruits could be predicted by using their chemical composition without doing feeding trials. The predictors for DDM were ADL, lignin, hemicelluloses and NDF. DDI was dependent on carbohydrate, fat ADF, hemicelluloses and NDF contents. On the other hand NEL was predictable from ADL, lignin and hemicelluloses while RFV was dependent on the carbohydrate, fat and NDF content.

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