DIETARY FIBRE IN NUTRITION AND HEALTH: THE NIGERIAN EXPERIENCE

O.S. Falade[1], B.A. Kolawole[2], I.O. Otemuyiwa[1] and S.R.A. Adewusi[1*]

[1]Department of Chemistry and

[2]Department of Internal Medicine, College of Health Sciences,

Obafemi Awolowo University,

Ile-Ife, Nigeria

ABSTRACT

Dietary fibre (DF) is an important component of plant foods and plays a significant role in health and nutrition. This paper reviews the analytical methods of dietary fibre determination, their short comings and possible improvement on the methods. Regression equations for the conversion of crude fibre (CF) and neutral detergent fibre (NDF) to DF were also reported. Nigeria and most of the developing countries of the world used to depend on plant foods, which are rich in fibre. However, rural-urban migration has deprived the farms of the much needed manpower and has led to the shortage of farm produce in the urban area. This has led to a change in the dietary habit in favour of refined foods. This paper also presents information on the Nigerian situation from different aspects. The contribution of plant foods rich in dietary fibre to the Nigerian diets in the 1960s is presented and compared to the current dietary fibre intake. The shift is then linked to increase in the incidence of dietary related diseases such as colon cancer, type II diabetes and cardiac diseases in Nigeria. The information so far in the literature show that ingestion of DF through the consumption of plant foods could go a long way in preventing or helping people with some medical conditions most especially Type 2 diabetes and colon cancer. Caution should be exercised in the promotion of an unbridled intake of dietary fibre especially in the developing countries because of its potential to reduce protein digestibility and making mineral elements unavailable. The results on the correlation between each of CF and NDF with DF revealed strong correlation coefficients (R^2) of 0.901 and 0.984, for CF and NDF, respectively.

* Author for Correspondence osfalade@oauife.edu.ng; Tel: +2348035603827

Keywords: Dietary fibre. Nutrition Therapy

INTRODUCTION AND HISTORICAL PERSPECTIVE

Dietary fibre is defined as the portion of plant foods that can not be digested by human digestive secretions in the digestive tract (Ders, 1999). Crude fibre on the other hand is defined as what remains of cell-wall constituents after treatment with acid, alkali, and alcohol. From the nutrition and health viewpoints, dietary fibre is more widely accepted as the appropriate term than crude fibre. Although dietary fibre is not digested by human digestive enzymes, it is digested by microorganisms in the colon (Bennett and Creda, 1996). Dietary fibre is made up of cellulose, hemicellulose, hexosan, pectin substances, gum, mucilage and lignin.

A more comprehensive definition was given in the American Association of Cereal Chemists (AACC) report of 2001 as "The edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fibre includes polysaccharides, oligosaccharides, lignin, and associated plant substances. Dietary fibres promote beneficial physiological effects including laxation, and / or blood glucose attenuation" (CFW, 2001).

Unrefined wild plant foods similar to contemporary hunter-gatherers have been reported to have low glycemic indices (Foter-Powell *et al.*, 2002). Mercader (2009) observed in his study on diets of Mozambican during the Stone Age and discovered several thousand starch grains on the excavated plant grinders and Scrapers that showed that wild sorghum was being brought to the cave and processed for food. Earlier studies (Mercader, *et al.*, 2008) also revealed starchy foods (cereals) to be the major component of the diets of people of the Niassa Rift, Mozambique. The excavated materials form where the information was obtained were date back to the Middle Stone Age. The investigation presumed to be middle to late Pleistocene. Their study revealed the consumption of seeds, caryopses, legumes, piths, and nuts.

The Paleolithic, caveman, diet is a reversion to the foods eaten by human prior to the advents of civilization, agriculture and technology (Audette and Gilchrist, 1999). The diet during the Stone Age is believed to consist largely of lean red meat and vegetation with animal meat contributing about 45 – 65 % of energy to the Paleolithic people (Audette and Gilchrist, 1999).

Among the Aboriginal of Australia, African and South America that survived into twentieth century, the rates of cancer, rheumatoid, arthritis, obesity, diabetes, osteoporosis, heart disease, and other conditions were observed to be remarkably low until they changed to modern diets (Audette and Gilchrist, 1999). It was also reported that the switched to modern diets happened about 10,000 years ago when it was discovered that many inedible plants could be made suitable for human consumption by cooking (Audette and Gilchrist, 1999).

TYPES AND METHODS OF ANALYSIS / CORRELATION BETWEEN DIFFERENT TYPES OF DIETARY FIBRES AND ANALYTICAL RESULTS.

Dietary fibre, which includes cellulose, hemicellulose, pectin, lignin, rubber and wax can be divided into soluble and insoluble fibres. Each of them performs different physiological roles as well as different effect on the nutritional quality of the plant foods (Bennett and Creda 1996; Falade *et al.*, 2005). Reliable analytical results on fibre content of plant foods were first published in the late nineteen seventies (Paul and Southgate, 1978). Before this time, “crude fibre” (CF) content was reported as the equivalent of dietary fibre. The crude fibre is known to under estimate the fibre content of samples (Southgate, 1976). The analysis of crude fibre (AOAC, 1984) is cheap and requires a short time to conduct.

Other Methods of Fibre Determination

The method of Van Soest and Mcqueen (1973) known as the neutral detergent fibre method (NDF) is used for the determination of insoluble fibre. The insoluble fibre is made up of cellulose, hemicellulose and lignin. This method is not suitable for samples with high starch content, because it was originally used for forages, its subsequent application to starchy foods and feeds, showed that starch interfered with the method (Van Soest *et al.*, 1991). The detergent methods have been observed to sometimes lead to over estimation due to the incomplete removal of starch, fats, and proteins (Robertson and Horvath, 1992). The problem with this method was solved by incorporating pancreatic amylase into the NDF method which removed the problem of over estimation due to starch (Mongeau and Brassard, 1982).

For the NDF method to be suitable for starchy plant foods, various modifications using amylase enzyme have also been reported (Mascarenhas–Ferreira, *et al.*, 1983). A major modification to the NDF method involves the initial treatment of the sample (in aqueous solution) with heat stable α-amylase followed by filtration before further processing. Another method used for removing starch from very difficult to treat samples was also described by Van Soest *et al.*, (1991). In the method, a sample is first treated with urea plus amylase and then continued as described below:

NDF Procedure (AACC, 1983)

The sample has to be dried, milled and passed through a 1.0 mm^2 aperture. The dried sample (1.0 g) is accurately weighed in to a 250 ml Erlenmeyer flask and 0.5 g of sodium sulphite added followed by 100 ml of neutral detergent solution and 2.0 ml of Decalin. The suspended solution is then heated to boiling in 5 – 10 min on hotplate. After boiling, the suspended solution is then refluxed for 60 min. The residue is filtered using pre-weighed glass crucible, washed with hot (90 – 100 ^{o}C) water followed by acetone wash. The washed residue is then dried at 103 ^{o}C overnight, cooled in desiccator and weighed. NDF is calculated using the following expression:

$$\% \text{ NDF} = \frac{\text{weigh of crucible and fibre} - \text{weigh of crucible} \times 100}{\text{Weigh of sample}}$$

Acid detergent fibre (ADF) method is also used to determine insoluble fibres. The method was reported not to be valid for fibre fraction for nutritional use or for the prediction of digestibility (Van Soest *et al.*, 1991). The procedure for this method is given below:

Acid Detergent Fibre Method [973.18] (ACOC, 1990)

Sample to be used must be dried to constant weight at 55 ^{o}C and ground to pass a 1.0 mm screen. Sample (Approx. 0.9 to 1.1 g) is placed into Berzelius beaker and 100 ml acid-detergent solution added. The suspended solution is then refluxed for about 60 min. The suspended solution is then filtered through a tarred fritted glass crucible using vacuum. The residue is later washed with hot water followed by acetone and dried for 3 hrs or overnight in forced-air oven at 100 ^{o}C and weighed. % ADF is obtained from the equation below:

$$\% \text{ ADF (DM basis)} = (W3 - W1 / W2 \times DM / 100) \times 100$$

W1 = tare weight of crucible in grams

W2 = initial sample weight in grams

W3 = dry weight of crucible and dry fibre in grams

DM = dry matter in grams

Recently, Perez-Hidalgo *et al.*, (1997) compared the values obtained for insoluble dietary fibre using enzymatic modified neutral detergent fibre (E-NDF) and the AOAC method (AOAC, 1995). The results showed that the accuracy of each method depends on the sample analyzed. The values obtained for kidney beans were not significantly different for both methods but differed for lentils (Perez-Hidalgo *et al.*, 1997). They also observed that the nitrogen determination stage can be omitted in E-NDF method because the crude protein content of the residue was insignificant (0.40 - 2.16 %) compared with CP (8.53 - 13.80 %) reported for the AOAC-method (Perez-hidalgo *et al.*, 1997).

The widely acceptable method for dietary fibre determination is the enzymatic - gravimetric method involving the enzymatic removal of starch and protein. This method mimics what happens in the digestive tract. The method provides an opportunity to determine both soluble dietary fibre (pectin, gums, and mucilages) implicated for most of the physiological properties of dietary fibre (Manisha *et al.*, 2000; Falade *et al.*, 2005) and insoluble dietary fibre (IDF) (Lee *et al.*, 1992).

Methods are also available for the determination of the components of water soluble and insoluble fibre such as hexoses, pentoses and uronic acids using gas – liquid or liquid chromatography (Southgate, 1969).

There is a growing concern that the total dietary fibre (TDF) method using the enzymatic - gravimetric method, (AOAC method 985.29, AOAC, 1990) over-estimates the dietary fibre content of some plant foods compared with some other enzymatic – chemical methods (Mongeau and Brassard, 1993, 1994). The higher value was attributed to the inclusion of undigested starch by this method (Englyst and Cummings, 1988; Marlett *et al.*, 1994). As a result of this over-estimation, (Theander *et al*, 1994) suggested that analytically enzyme - resistant starch should be included in the results of dietary fibre since the physiological properties of this enzyme-resistant starch are similar to some fibres.

There are now two official methods of dietary fibre analysis (AOAC method 985.29 and AOAC method 991.43 (AOAC, 2003). Both methods are however based on the enzymatic–gravimetric method. The principle of the two methods is based on the removal of fat followed by treatment with heat stable α-amylase, protease and amyloglucosidase to degrade proteins and starch. The hydrolytic step is followed by the precipitation of soluble fibre (DF) with 95 % ethanol. The precipitate is then filtered and the weight noted. Total dietary fibre (TDF) is later calculated by subtracting the weight of protein and ash from the weight of the residue.

In 2001, American Association of Cereal Chemists (AACC) included fructans in the definition of DF. It was accepted that DF should include short-chain polysaccharides that are soluble in 78 % ethanol (AACC, 2001) which include fructans, inulin and oligofructose. These compounds are believed to possess many of the physiological properties noted for DF (Tsai *et al.*, 2007). Fructans, for example, are believed to possess health properties that are beneficial to diabetic patients because they reduce glycemic load and index (Tsai *et al.*, 2007). The compounds are also prebiotic (Roberfroid and Delzenne, 1998). Some of these fructans have been reported not to be precipitated by the addition of alcohol to the hydrolysate in the AOAC method 985.29 (Tsai, *et al.*, 2007) resulting in under-estimation of the DF. As a result of this short coming, the new AOAC method 999.03 (AOAC, 2003) was developed for separate determination of fructans and DF is thence taken as the sum of DF determined by AOAC method 985.29 and the fructans determined by the AOAC 999.03 method. This technique has also been reported to over estimate DF because fructans already precipitated under method 985.29 will be estimated again under method 999.03 (Tsai *et al.*, 2007). This problem was solved by Tsai *et al.*, (2007) by combining the two methods. In this new method, the filtrate from method 985.29 was used under the method 999.03 to determine fructans. This combined method was observed to give more accurate values with reasonable recovery of about 98 %.

Correlation between Different Types of Dietary Fibre Methods

It is instructive to compare the result obtained by different methods of fibre analysis from the same laboratory. Thus, dietary fibre content of some Nigerian staple foods was analysed using three different fibre methods (Tables 1). Crude fibre was determined by AOAC method (AOAC, 1990). Neutral Detergent fibre (NDF) was determined by the Van Soest (1963) method, while dietary fibre was by the gravimetric method of Lee *et al.*, (1992) using a combination of three enzymes (heat-stable α-amylase, protease solution, and amyloglucosidase solution) for the digestion. The aim is to develop correlation equations which can be used to convert values from any of these two methods to Dietary fibre without going through the cost and rigor of gravimetric method.

From the results presented on the table 1, crude fibre method grossly under estimated fibre content of these samples. This is in agreement with earlier observation (Southgate, 1976). NDF on the other hand was observed to over estimate dietary fibre in all the samples with the accepting of *Acacia colei* and millet seeds. In *A. colie* seed, the value was lower in NDF than dietary fibre while in millet, there was no significant difference in the values obtained in both methods. The over estimation observed in most of the samples has been earlier attributed to inability of this method to effectively remove soluble carbohydrate (starch) from sample (Robertson and Horvath, 1992). It is interesting to note that the NDF method gave lower value for *Acacia colei* seed than the dietary fibre method. This is contrary to the earlier observation that NDF usually over estimate fibre (Van Soest *et al.*, 1991). The reason for this observation is not clear but could be due in part to the fact that *Acacia* is non-starchy food but a leguminous plant. It has also been observed earlier that the accuracy of each method depends on the sample analyzed (Perez-Hidalgo *et al.*, 1997). For example, the starch content of *Acacia colei* was lower than that of Sorghum seed which was 25.6 and 73.8 % respectively (Falade *et* *al.*, 2005, Hubband and Earle, 1950). The high starch content of these cereals could account for the higher NDF values obtained in this study. This is in agreement with the earlier observation that the presence of substantial amount of starch lead to overestimation of NDF (Van Soest *et al.*, 1991).

Correlation between methods

The gravimetric method of Lee *et al.*, (1992) is very expensive. The cost per analysis is estimated to be about fifteen times that of crude fibre method. Apart for the cost effect of this method, it is equally time consuming. As a result of these, the values obtained from gravimetric method were correlated with each of the other two methods (Crude fibre and NDF).

The crude fibre and neutral detergent fibre results (Table 1) were separately correlated with dietary fibre results (Table 1). The following equations were obtained:

$$y = 17.390\,x - 3.984 \qquad (1)$$

$$y = 1.129\,x - 3.234 \qquad (2)$$

Equation (1) is for the conversion of Crude fibre to Dietary fibre and with the correlation coefficient (R^2) value of 0.901 while equation (2) is for the conversion of NDF to dietary fibre with correlation coefficient (R^2) value of 0.980. y = dietary fibre, and x = either crude fibre or NDF value

Dietary fibre content of some West African plant foods

The dietary fibre content of some West African plant foods is presented in Table 3. Of all the plant foods reported on Table 3, *Acacia* has the highest dietary fibre content followed by maize and white bread. Cowpea and plantain were moderate while yam was low.

Dietary fibre intake in Nigeria

Mbofung *et al.*, (1984) reported a dietary fibre intake of 63 and 69 g / head / day for urban and rural Nigerian women respectively. This fibre intake was significantly higher than the recommended dietary allowance (RDA) of between 25 – 35 g TDF / day (Anderson *et al.*, 1990). Recently, Adegoke *et al.*, (2006) reported a dietary fibre intake of 40.5 and 54.2 g / day for female and male students of a Nigerian university respectively (table 4). The high fibre intake of these Nigerian students was linked to the consumption of cereals, roots and tubers which are the main staple foods in Nigeria (Adegoke *et al.*, 2006).

This dietary fibre intake in Nigeria was higher than the 20 g / day reported for Australians (NHMRC, 1991) and higher than the RDA value, the fact remains that dietary fibre intake of Nigerians is reducing. This can be attributed to the adoption of western dietary customs (consumption of refined food products with less DF) most especially in the urban regions of Nigeria.

Our studies on *Acacia* seeds revealed these seeds to be rich in dietary fibre most especially soluble fibre (Adewusi *et al.,* 2003; Falade *et al.,* 2005; Adewusi *et al.,* 2006).

The incorporation of these seeds in to the diets of Nigerians with no doubt increase the dietary in take of fibre. For example, the incorporation of *A. colei* seed in to the traditional diets of Maradi people of the Niger Republic lead to an increase in dietary fibre intake of 82 g /day to 170 g / day, representing about 107 % increase (Adewusi *et al.,* 2006).

EFFECT OF DIETARY FIBRE ON NUTRITION AND HEALTH

Dietary fibre and specific medical conditions

Impact of Dietary Fibre on Glucose and Lipid Metabolism

Virtually all treatment strategies for diabetes include some form of dietary modification or another. Diet and exercise are thus regarded as the most important modalities in the therapy of diabetes and have been considered in its management for centuries. Because of the heterogeneity of the diabetic syndromes, the diabetic diet is tailored according to age, nutritional status, severity of the metabolic disorder, physical activity, education, social, cultural, and economic factors as well as the presence of any associated problems such as hyperlipidaemia, hypertension or renal disease (Jenkins *et al.*, 1980). Traditionally, recommendations have included limitation of the intake of simple carbohydrates (monosaccharides and disaccharides) and increased caloric intake from complex carbohydrates (polysaccharides). However, among various simple and complex carbohydrates, the postprandial glycaemic response varies considerably. One of the factors that affect the glycemic response of a meal is the fibre content of the meal.

Dietary fibre thus has beneficial effects on glucose control and circulating lipid levels possibly through delayed gastric emptying, altered transit time in the small intestine, insulation of carbohydrates from digestive enzymes, and digestive enzyme inhibition (Jenkins *et al.*, 1983).

Dietary fibre has been shown to affect the rate and extent of starch degradation. In particular, soluble DF has been shown to reduce the rate of starch digestion and alter the rate of glucose absorption (Pereira *et al.*, 2005; Wood *et al.*, 1994). Research has focused on the use of guar gum in food systems as a postprandial glucose modifying ingredient. The viscosity-altering behaviour of these soluble DFs within the small intestine account for some of these effects, however, the DFs also appear to alter the structure of food and hence the accessibility of the starch granules to the amylase enzymes (Brennan *et al.*, 1996; Tudorica *et al.*, 2002).

High fibre diets have been advocated for and recommended in the treatment of diabetes (Miranda & Horwitz, 1978). Perhaps, with the exception of green leafy vegetables, fibre rich foods are predominantly high carbohydrate foods, for example cereals and legumes. Lack of palatability and possible effects on inducing mineral or vitamin deficiency because of bile acid interaction are some of the disadvantages of high dietary fibre.

Many of the diets recommended for balanced nutrition include a large proportion of dietary fibre (DF). Current recommendations suggest an intake of 20 - 40 g dietary fibre per day (ADA, 2006).

The Nigerian Experience

While most studies on which present recommendations are based were conducted amongst Caucasians, nevertheless a few studies from Nigeria have also shown the same benefits from the consumption of fibre derived from local food sources. In an 8 weeks study, Adebayo *et al.* (2006) studied the effects of local fruits and vegetables on cardiovascular risk factors in hypertensive Nigerians. They found that though there was no significant difference in the body mass index and HDL - cholesterol at the end of the eighth week, there was significant reduction in serum triglycerides, total cholesterol, and LDL-cholesterol. In another study, Nwosu *et al.* (2006) tested the hypolipaemic effect of soluble fibre supplementation using the seed of the locally available tree plant, A*fzelia africana*. They fed 13 Nigerian type 2 diabetic patients with unsupplemented and fibre supplemented standardized diet for the first 2 days and subsequent 4 days respectively. The results showed a significant reduction ($P<0.05$) in mean fasting TG, LDL-C and improvement in HDL / TC ratio following a 4 day supplemented meal. These studies corroborate previous reports that the exploitation and incorporation of soluble fibre in diabetic and hypertensive diets reduced lipaemia and by extension cardiovascular risk.

In a more recent and perhaps larger study, we studied the effect of a formulated high caloric fibre diet on the glycaemic and lipid profile of tablet treated type-2 Nigerian diabetics (Ikem *et al.*, 2007). 52 type 2 diabetics (26 men and 26 women) were assigned to either an intervention (35) or control group (17). Each subject in the intervention group consumed a diet providing at least 40 g of fibre per day while subjects in the control group were fed a regular diet. The effect of both diets on glucose and lipid profile was then tested at 4 and 8 weeks.

One way repeated measures analysis of variance for the follow up period indicated a significant lowering of waist circumference p = 0.002, fasting blood glucose (FBG), 2 h post prandial glucose, total cholesterol, triglyceride, and LDL-C (p = 0.000 in all cases) by the third visit in the intervention group. At the end of the third visit, the mean FBG decreased by 4.9 ± 2.7 mmol / L 95 % CI - 5.8 to - 3.9 in the intervention group and by 3 ± 2.8 mmol / L 95 % CI - 4.5 to - 1.5 in the control group p = 0.02. 23 (65.7 %) intervention group subjects had attained FBG levels ≤ 7.0 mmol / L by the third visit. None of the control subjects had their FBG lowered below 7.0 mmol / L by the third visit. Plasma glucose concentration 2 h after meal, plasma TC, TG and LDL-C decreased significantly more in the intervention group than among those in the control group. By the second visit, all the patients in the control group had their oral hypoglycaemic drugs increased to achieve glucose control while 29 (82.9 %) persons in the intervention group had their drugs increased in a similar fashion. By the third visit, 8 (47.1 %) control subjects had a further increase in the dose of their sulphonylurea while all but 2 (5.7 %) patients in the subject group had achieved normoglycemia.

Based on the above observations, it was concluded that consumption of a high fibre diet provided mainly through soup thickeners and vegetables by newly diagnosed Type 2 diabetic Nigerian patients being treated with oral hypoglycaemic agents resulted in early attainment of normoglycaemia and improved glycaemic and lipid profile compared with a conventional diet. These fibre sources are cheap, palatable, free of untoward effects and readily adaptable. In a resource limited setting as in Nigeria where cost considerations are of paramount importance, the oral hypoglycaemic sparing effect of such diets are indeed an added benefit. These observations underscored the need for our dietary guidelines to include and insist on specific recommendations on increased utilization of dietary fibre.

The results of this study corroborated those of Simpson *et al.*, (1981) who demonstrated that a high-carbohydrate / high-fibre diet can be implemented by diabetic patients in their usual home setting without major feasibility problems and with the same beneficial metabolic effects as observed in hospitalised patients. It remains to be determined if high-carbohydrate / high-fibre diets are uniformly effective in all subjects. One thing that is clear, however, is that most patients derive at least some benefit. Because individuals with diabetes spend a longer time in the postprandial than fasting state, it follows that their liability to glucose-induced tissue damage might correlate more with postprandial glucose levels (Anderson and Akanji, 1991). Postprandial glucose levels are effectively reduced by DF.

Dietary Fibre and Colorectal Cancer

Diet is clearly linked to both the risk for and incidence of colorectal cancer. It has been estimated that approximately 70 % of the causation of colorectal cancer is due to dietary factors and that an optimal dietary approach might prevent this disease (WCRF, 1997). The idea that increased consumption of fibre might be associated with reduced incidence of colorectal cancer was highlighted by Burkitt (1971). Correlative studies, case control studies, and prospective studies have since been conducted to test this hypothesis. The methodology for assessing dietary intake however varied between these studies. They included the 24 h recall method, the three to seven day food dietary method, and food frequency questionnaires which on their own may not be completely accurate (Kim, 2000). Trock *et al.*, (1990) reported a meta-analysis of 16 case control studies and found an odds ratio for colorectal cancer of 0.57 (95 % confidence interval 0.50 – 0.64) for the highest compared to the lowest quartile of fibre intake. The nature of the study did not permit discrimination between fibre types or sources. Most of the published case control studies indicated either a strong or moderate protective effect of dietary fibre or fibre rich foods, and thus support the fibre hypothesis. The effect is remarkably consistent and a fibre consumption of approximately 30 g per day is associated with an approximate 50 % reduction in risk for developing colorectal cancer (Young *et al.*, 2005).

In an effort to obtain more direct evidence under highly controlled conditions, investigators have designed prospective intervention studies using a range of biomarkers to predict the effect of DF on oncogenesis. Biomarkers are biological events which are considered to be related to risk for development of colorectal cancer. Of the biomarkers available, adenomatous polyps are likely to be the most relevant to cancer itself. Some of the studies have been collectively reviewed (Kim, 2000). In a comprehensive trial, patients with familial adenomatous polyposis and ileo-rectal anastomosis, were offered a grain fibre supplement (22.5 g / day) over a 4-year period and then compared to a base supplement of 11 g / day. The intervention significantly inhibited the development of rectal polyps in those who consumed the fibre (DeCosse *et al.*, 1989). Generalization of this result was limited because the end points had not involved cancer. The adenomas used as endpoints were at varying stages of progression along the oncogenic pathway. It also needs to be considered that dietary fibre might be most protective when consumed in the natural food source rather than as a synthetic supplement (Fergusson and Harris, 1999). After a critical review of the information available in 2000, the American Gastroenterological Association (Kim, 2000) concluded that on the basis of these studies it was reasonable to recommend a total dietary fibre intake of at least 35 g / day.

Concerning the mechanism of protection of DFs, Burkitt's (1971) initial hypothesis was that the mechanism was physical. Fibre increased faecal bulk, diluted carcinogens, hastened transit, and therefore reduced contact time between carcinogens and the luminal epithelium. Since then, additional mechanisms have emerged concerning fermentation, the prebiotic functions of dietary fibre, and certain general metabolic effects (Young *et al.*, 2005).

The adoption of western type dietary has been observed to be responsible for incidence of colorectal carcinoma of the immigrants black American that is comparable to Caucasians (Burkitt *et al.*, 1971). The influence of diets on colon cancer has been well documented (Burkitt, 1971). The rare case of colorectal cancer among rural Africans has also been attributed to the consumption of little meat and high fibre consumption (Burkitt, 1971). Boyle and Longman (2000) have also observed inverse correlation between consumption of dietary fibre and colon cancer.

Few studies have assessed the contribution of dietary fibre to the prevention of colorectal cancers in Nigeria. These cancers are generally regarded as less common in Africans and developing countries because of lower per capita income and higher dietary fibre consumption. Evidence from literature on the subject however suggested that this trend may be changing. In a clinicopathological study of 526 patients with histologically proven malignant colorectal neoplasm seen at the University College Hospital, Ibadan between 1971 and 1990, colonic malignancies increased by 81 %, whereas rectal malignancies decreased 16.1 % in frequency (Iliyasu *et al.*, 1996). Factors including incomplete records and missed cases may explain this discrepancy. Furthermore, Akinbami *et al.*, (1995) also observed from the same institution among 410 apparently healthy children aged 6 months to 5 years that stool frequency varied from once every other day to five times a day. 95 % of the children studied opened their bowels 1 - 3 times a day while the mean mouth to anus transit time in a subgroup of 98 children was 18.3 hours. They attributed this finding to the fact that majority of the children ate a predominantly high fibre residue diet. Colorectal carcinoma has been observed to be on the increase in Nigeria (Irabor, 2011). This was attributed to adoption of western type life style (diets), which are low in fibre but rich in red meat and fat.

Dietary Fibre and Inflammatory Bowel Disease

The term “inflammatory bowel disease” (IBD) comprises two closely related pathologies, ulcerative colitis (UC) and Crohn’s disease (CD), which are characterized by chronic and spontaneously relapsing inflammation of the gut. UC affects only the large bowel, and the inflammatory process is confined to the mucosa. CD may affect any part of the bowel, from the mouth to the anorectum, and it is not confined to the lining of the bowel. It affects also the entire bowel wall to form abscesses and fistulas (abnormal connections between the lumen of the bowel and other organs and / or the surface of the skin). It may also present with bowel obstruction. Although much progress has been made in the understanding of human IBD pathogenesis, its precise aetiology still remains unknown and involves a great number of factors, including genetic, environmental, microbial, and immunological factors (Fiocchi, 1998). Thus, an exacerbated inflammatory response of the intestine results from an inappropriate reaction towards a luminal agent, most probably driven by the intestinal microflora (Farrell, 2002). It also up-regulate the synthesis and release of different pro-inflammatory mediators, including reactive oxygen and nitrogen metabolites, eicosanoids, platelet activating factor, and pro-inflammatory cytokines (Sartor, 1997).

Probably, the first approach to dietary fibre as a potential therapeutic option in human IBD was performed by Davies and Rhodes (1978), who evaluated the impact of dietary oat bran supplementation to UC patients in maintaining remission. Dietary fibre exerts clinical benefits in patients with IBD, since it has been shown to maintain remission effectively and reduce colonic damage. This is achieved by promoting changes in the colonic lumen of the host; first, by facilitating the production of short chain fatty acids (SCFAs), which are able to modulate the immune response in the different cell types residing in the inflamed intestine. Secondly, by actively modifying the intestinal microbial balance towards non-pathogenic bacteria. It is not yet established which of the two mechanisms predominates in the beneficial effects exerted by dietary fibre in IBD.

Long Term Safety Considerations

The commonest side effects associated with fibre intake are diarrhoea, flatulence, bloating, anorexia, and abdominal pain (Cummings & Englyst, 1987; Van Duyn *et al.*, 1986). The frequency of these side effects can usually be reduced by gradual pashed increases in fibre intake. Initial anxieties about the likely effects of prolonged fibre intake on vitamin and mineral balance in humans have largely been dispelled by the demonstration of many investigators that fibre intake for periods greater than 6 months had no significant adverse effects on trace element and vitamin homeostasis (Garg *et al.*, 1990; Van Duyn *et al.*, 1986). Many practitioners still consider adding vitamin and mineral supplements to the diet of their patients (Anderson and Akanji, 1991).

Effect of Dietary Fibre on Digestion in Monogastric Animals including Man

The role of fibre in health and nutrition has received much attention in the recent years. For example, study on the gastric disappearance of dietary fibres revealed that cellulose was less digestible than hemicelluloses while pectin, a soluble fibre was completely digested (Fetzer *et al.*, 1979). The negative effect of dietary fibre most especially insoluble fibre has been reported to slow down the rate of digestion and absorption of food (Anderson and Akanji, 1991). This effect has been linked to the improvement in the postprandial glycemic response and insulin concentrations (Anderson and Akanji, 1991). It is well documented that soluble, viscous types of dietary fibre, such as pectin, reduce the glycemic response when incorporated into meal. This has been attributed to delay of gastric emptying (Wahlqvist, 1987) and thus the positive effect of DF on diabetes mellitus.

Fahey (1979) and Baird *et al.,* (1974) used crude fibre, cellulose and citrus pulp as sources of fibre to investigate effect of fibre on protein digestibility and observed 1.0, 1.1 and 1.6 % decrease in crude protein (CP) digestion for each 1.0 % increase in fibre content of the diet, respectively. Adewusi and Ilori, (1994) also observed that increase in NDF from 5.6 to 11.2 % lead to 0.93 and 1.09 % decrease in crude protein digestion for each 1.0 % increase in NDF content provided by white sorghum spent grain and red sorghum spent grain, respectively.

Since monogastric animals lack enzymes to digest dietary fibres, the fibres are fermented, leading to the formation of short chain fatty acids (SCFA) and other products (Stephen and Cummings, 1980). The fermentation of fibre was also reported to increase fecal output by stimulating microbial growth (Stephen and Cummings, 1980). The studies on fibre digestion in chickens revealed that about 15 to 33 % of graminaceous fibre was fermented (Longstaff and McNab, 1986) while none of the insoluble fibre from lupin seeds was fermented (Carve and Leclercq, 1985). More dietary fibres of different types are fermented by rats and humans (Graham *et al.*, 1985).

Dietary fibre has been reported to negatively affect protein digestibility in rat (Adewusi and Ilori, 1994). Falade, *et al.*, 2008 observed low true protein digestibility when *Acacia colei* seed was incorporated into some Nigerian staple foods. The low digestibility observed was attributed to high dietary fibre content of *Acacia colei*. Low *in-vitro* starch digestibility of *Acacia* seeds has been earlier reported in our laboratory (Falade *et al*., 2005) which was attributed to soluble dietary fibre because of high negative correlation ($r = -0.64$, $p < 0.05$) observed between soluble fibre and starch hydrolysis.

Effect of Dietary Fibre on Mineral Availability

Mineral deficiency (especially iron) is still a public health issue in west Africa countries and most especially Nigeria where the population depends mainly on carbohydrate foods, vegetables and very little animal protein. Mineral availability from plant food sources is usually low (Adewusi and Falade, 1996, Adewusi *et al*., 2003). This has been attributed to anti-nutritional compounds such as phytate, tannin and oxalate (Adewusi and Falade, 1996; Osuntogun *et al*., 2004) and dietary fibre (Falade *et al*., 2005; Fernandez and Phillips, 1982). Recently, dietary fibre survey of adolescent university students of Obafemi Awolowo University, Ile-Ife, Nigeria with age that ranged between 18 and 25 as well as adults revealed that 41.3 and 49 % of adolescent and adults, respectively consumed fruits on a regular basic (Dare *et al*., unpublished results). In addition, 60 and 50 % of the adolescent and adults, respectively consumed whole fruits especially oranges, grapes, pineapple and banana all of which contain significant levels of dietary fibre (Falade *et al*., 2005). In Nigeria, fruits can be consumed in two main forms; the juice can be extracted and taken or just sucked out of the fruit as in oranges. On the order hand, whole fruit minus the peel and the seeds can be eaten (Falade *et al*., 2005). The latter form would increase the total dietary fibre intake.

The effect of the consumption of whole fruits on the mineral availability from cowpea and vegetable composite diets was investigated in our laboratory (Falade *et al*., 2005). The results revealed that banana and orange enhanced iron availability from amaranthus but grape fruit and pineapple impaired iron availability. All the fruits impaired iron and copper availability from cowpea. The impairment of these minerals was attributed mainly to soluble dietary fibre as reported earlier by other investigators (Fernandez and Phillips, 1982). The minerals with enhanced availability was observed to be due to ascorbic acid content in the fruits, but this seemed to be antagonized by the dietary fibre content when whole fruit is eaten. The positive effect of dietary fibre intake through whole fruit consumption should be balanced against its apparent adverse effect on mineral availability especially in populations at risk of mineral deficiency.

The binding capacity of fibre to minerals has been observed to be pH dependent; for example, minimal binding was observed at pH 4.0 but rose rapidly above pH 5.0 to a maximum at pH 7.0 (Reinhold *et al*., 1981). This indicated that although dietary fibre intake has tremendous benefits for people with diseases such as type 2 diabetes, colon cancer and cardiovascular diseases, its intake could also reduce the essential mineral status of people. Therefore, in recommending intake of high dietary fibre, caution must be exercised most especially the people at risk of mineral deficiency.

World Health Organization (WHO) has reported that 80 % of all cardiovascular disease, 30 % of all cancer and 90 % of all Type 2- diabetes could be prevented by good eating habit that is through healthy diets, physical activity and abstinence from smoking (WHO, 2003). For Example, Diets low in fibre content have been implicated in many diseases such as coronary heart disease (CHD), hiatus hernia, tumors and cancer of the colon and obesity (Burkitt, *et al.*, 1974).

CONCLUSIONS

In conclusion, the reversal to traditional African diets rich in dietary fibre will go a long way in reducing diseases associated with the consumption of Western diets that are rich in refined foods. This will no doubt reduce the huge budget on maintaining health of the populace. The nation's working class will also be healthy and more productive.

The use of the regression equations in this study would also make it possible to generate data on dietary fibre of plant foods without going through the rigor of the procedures for the determination of DF. The high cost of analysis of DF will also be avoided because CF and NDF data can be converted to DF.

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Table 1: Fibre content of same Nigeria stapes foods and *Acacia colei* seeds (g/100g) on dried weight basis.

Food stuff	Crude fibre	Dietary fibre	NDF [a]
White acha 1	0.3	1.7	5.9
White acha 2	0.2	0.6	2.5
Brown fonio	0.2	0.5	1.9
Millet	0.7	9.5	9.6
Red sorghum	1.1	9.6	13.3
White sorghum	1.1	9.8	13.6
Acacia colei	1.5[a]	29.1	27.1
Maximum std. errors	0.1	0.2	0.7

Source: Falade *et al.*, 2008; NDF is neutral detergent fibre; [a] unpublished result

Table 2: Dietary fibre obtained by calculation using Equations 1 and 2.

Food stuff	DF calculated From crude fibre	DF calculated from NDF	Experimental DF
White acha 1	1.2	3.4	1.7
White acha 2	- 0.5	- 0.4	0.6
Brown fonio	- 0.5	- 1.1	0.5
Millet	8.2	7.6	9.5
Red sorghum	15.1	7.6	9.6
White sorghum	15.1	7.8	9.8
Acacia colei	22.1	29.6	29.1

Table 3: Crude and Dietary Fibre Content of Some West African Plant Foods (%)

Food stuff	Dietary Fibre (%)	Crude fibre (%)	Country	No of samples	Source
Yam (*D. alata*)	1.20	-	Cameroon	23	Egbe & Trede (1984)
Yam (*D. esculenta*)	-	0.21	Nigeria	1	Ologhobo (1985)
Yam (*D. rotundata*)	0.87	-	Cameroon	9	Egbe & Treche (1984)
Yam (*D. rotundata*)	-	0.34	Nigeria	1	Ologhobo (1985)
Cassava	-	0.9	Nigeria	Several	Ekpenyong (1984)
Acacia tumida	30.1	-	Nigeria	3	Falade *et al.*, (2005)
African locust bean (*P. biglobosa*)	-	11.7	Nigeria	1	Omafunbe *et al.*, (2004)
Melon seeds (*C. vulgaris*)	-	15.8	Nigeria	1	Omafunbe *et al.*, (2004
Banana[1]	1.3	-	Nigeria	1	Falade *et al.*, (2005)
Grade fruit[1]	1.7	-	Nigeria	1	Falade *et al.*, (2005)
Orange [1]	1.5	-	Nigeria	1	Falade *et al.*, (2005)
Pineapple[1]	1.3	-	Nigeria	1	Falade *et al.*, (2005)
Amaranthus [2]	3.6	-	Nigeria	1	Falade *et al.*, (2005)
Cowpea[3]		-	Nigeria	1	Falade *et al.*, (2005)
While rice (cooked)	2.8 ± 0.2	-	Nigeria	1	Adegoke *et al.*, (2006)
Jollof rice	2.6 ± 0.3	-	Nigeria	1	Adegoke *et al.*, (2006)

Fried rice	3.2 ± 0.6	-	Nigeria	1	Adegoke *et al.*, (2006)
Fesh-maize (cooked)	10.5 ± 1.0	-	Nigeria	1	Adegoke *et al.*, (2006)
White bread	9.3 ± 0.7	-	Nigeria	1	Adegoke *et al.*, (2006)
Raw Cowpea (*V. unguiculata*)	5.2 ± 0.1	-	Nigeria	1	Adegoke *et al.*, (2006)
Fermented cassava "fufu *Mannihot esculatenta*	2.8 ± 0.5	-	Nigeria	1	Adegoke *et al.*, (2006)
Cassava meal "Eba"	0.9 ± 0.3	-	Nigeria	1	Adegoke *et al.*, (2006)
Cassava flour (white "amala")	2.1 ± 03	-	Nigeria	1	Adegoke *et al.*, (2006)
Fried ripe plantain (*Musa sinensis*)	5.2 ± 0.4		Nigeria	1	Adegoke *et al.*, (2006)

[1]Values are on wet weight basis

[2]Values are on wet weight basis (Blanched vegetable)

[3]The samples were dried at 50 ^{o}C prior to analysis

Table 4: Mean Dietary Fibre Intake of Subjects from Different Nigerian Foods.

Food source	Fibre Intake	
	Male (g / day)	Female (g / day)
Cereals	25.9 ± 10.8	23.6 ± 8.10
Roots, tubers and plantain	13.4 ± 6.8	8.3 ± 3.5
Legumes and nuts	9.2 ± 4.3	4.7 ± 2.7
Vegetables and fruits	5.7 ± 2.9	3.9 ± 2.1
Total	54.2 ± 13.7	40.5 ± 8.5

Source: Adegoke *et al*., 2006