Z Lebensm Unters Forsch A (1998) 207:105–109

ORIGINAL PAPER

J. Serra Bonvehí · M. Aragay Benería

Composition of dietary fibre in cocoa husk

Received: 19 December 1997 / Revised version: 27 February 1998

Abstract This paper describes the total non-starch polysaccharide (NSP), soluble and insoluble dietary fibre (SDF and IDF) content of processed cocoa husk (cocoa butter <3 g/100 g) determined according to Englyst's enzymatic-chemical procedure. In addition, fibre values were determined by measuring the levels of the composite sugars by spectrophotometry and gas chromatography methods, and the fractions acid-detergent fibre, neutral-detergent fibre, crude fibre, Klason lignin, starch, crude protein, ash, fat, water content, and water-holding capacity (WHC). The NSP content was 43.8 ± 2.32 g/100 g (28.34 g/100 g IDF plus 15.60 g/100 g SDF), the mean soluble fibre concentration was 35.5% of total fibre. Klason lignin content, estimated gravimetrically, was 13.7 ± 1.8 g/100 g. Cellulose (19.7 ± 1.48 g/100 g) and uronic acids (12.4 ± 1.35 g/100 g) were the main type of IDF and SDF substances, respectively. The analysis of neutral sugar constituents showed the presence of glucose, the predominant sugar, followed by arabinose, galactose and xylose. The WHC was 3.62 ± 0.47 g water/g cocoa husk.

Key words Cocoa husk · Dietary fibre · Insoluble fibre · Soluble fibre · Cellulose

Introduction

There are a number of reports of positive effects associated with an increase in dietary fibre intake. These include a reduction in the incidence of ischaemic heart disease, diabetes, constipation, diverticulitis, appendicitis, varicose veins, colonic-rectal cancer, obesity, and gallstones [1, 2]. It has been suggested that a deficiency in dietary fibre plays a major role in the development of a wide range of diseases, and as a result many health organizations have recommended an increase in the dietary fibre intake of most diets currently consumed [3]. In recent years, the nutritional effects of dietary fibre have become apparent. Fibre is composed of remnants of plant cell walls that are not hydrolysed by alimentary enzymes in man. There are several methods for determining dietary fibre; these vary in complexity and speed of execution.

Cummings and Englyst [4] stated that for analytical purposes dietary fibre should be defined as the sum of the non-starch polysaccharides (NSP) in food. Since lignin is not a polysaccharide, it is not included in this definition. This exclusion is defensible on the grounds that lignin is a very minor component of the human diet, has physiological effects very different from those of NSP, and is difficult to determine accurately. Other plant materials such as polyphenols (PP), resistant protein, and resistant starch (RS), which are resistant to digestion are also excluded. Lichon and James [5] established a possible definition of dietary fibre as NSP, Englyst lignin, and RS. PP and organic acids are present in cocoa husk, with differing effects in the intestine depending on their solubilities [6–8].

To meet the interest and concern generated by the epidemiological association between a wide variety of diseases and a chronic low fibre diet, several forms of fibre have appeared in the marketplace. The dietary fibres most often consumed come from fruit, cereals, vegetables, and legumes [9]. Slavin [10] found that humans consume 20–40 g/day of dietary fibre. Fiber intake from fruit and vegetables has increased at the same time as the fibre intake from cereals has decreased. In spite of a selective and high consumption of fibre, it is difficult to know in advance the physiological properties of the fibres consumed, which depend on the vegetal tissue of origin and the modifications produced by the manufacturing and cooking processes. These changes can give rise to a decrease in the total fibre

J. Serra Bonvehí (✉)
Research and Development Department of Nederland, S.A., P.O. Box 34, E-08890 Viladecans, Barcelona, Spain

M. Aragay Benería
Agricultural and Food Laboratory, Generalitat of Catalonia, E-08348 Cabrils, Barcelona, Spain

content or to a change in the insoluble/soluble fibre ratio [11]. Cocoa husk is considered to be an important source of dietary fibre. Cocoa husk pigment has been widely utilized in pharmaceutical applications with antiviral activity [12]. It is a fibrous food, difficult to grind and indigestable, that constitutes approximately 44% (w/w) of the cocoa husk, and only 11% of the cocoa cake [13]. Literature surveys on the composition and practical uses of cocoa husk have been carried out and the industrial utilization of cocoa husk has been discussed recently [14–17]. The occurrence of pectin in cocoa husk waste and cocoa bean pulp has been established [18, 19]. The aim of this paper is to determine the NSP content of processed cocoa husk obtained by the Englyst procedure, and the composition of different fractions, as alternative sources of dietary fibre.

Materials and methods

Samples. Twelve samples of unroasted cocoa husk of the main varieties of cocoa beans (*Theobroma cacao* L.) cultivated in Ivory Coast, Nigeria, Cameroon, Colombia, Ecuador, Guinea and Brazil were studied (Table 1), after previous industrial extraction of cocoa butter from well-winnowed cocoa nib (cotyledon) by expeller pressing and by solvent extraction. All samples were ground to pass a 0.3-mm screen.

Moisture. Water content was determined using 5 g cocoa husk in a conventional kiln at 103–105 °C for 3–4 h, and drying to constant weight [20].

Crude protein. Non-protein and protein nitrogen were determined by conventional Kjeldahl digestion using a copper catalyst. The ammonia was distilled and collected in a solution of boric acid which was then titrated against a standard acid. Digestion and distillation were carried out using the Kjeltec apparatus (model 1OO2, Tecator AB, Höganäs, Sweden). Protein content was calculated as total Nx6.25.

Cocoa butter. Samples of 4 g cocoa husk were extracted with petroleum ether (40–60 °C) for 6 h using a Soxhlet apparatus with previous acid hydrolysis [20]. Fat was determined as the difference in weight of dried samples before and after the extraction.

Ash. Ash percentage was measured by heating, overnight at 500–550 °C in a furnace, to constant mass [20].

Table 1 Cocoa husk sampling: site of origin of samples

Sample no.	Country
1	Ivory Coast and Nigeria
2	Ivory Coast and Nigeria
3	Ivory Coast and Nigeria
4	Nigeria
5	Cameroon
6	Cameroon
7	Ivory Coast
8	Colombia
9	Colombia
10	Ecuador
11	Cameroon and Guinea
12	Brazil

Pre-treatment of the sample for analysis of dietary fibre. A portion of each sample was weighed, dried at 103–105 °C for 3–4 h and reweighed to determine the dry weight. Those samples that contained between 90% and 100% dry matter and less than 5% cocoa butter were analysed for dietary fibre.

Dietary fibre. The Englyst procedures utilized determined total, soluble (SDF) and insoluble dietary fibre (IDF) as NSP, in 90–100 mg cocoa husk, using enzymatic-chemical methods (Englyst Fiberzym kit; Novo Nordisk Bioindustries, UK). Starch was dispersed with dimethylsulphoxide and subsequently hydrolysed by incubation with amylase and pullulanase. After enzymatic digestion of the protein and precipitation of NSP with ethyl alcohol, the starch-free residue was hydrolysed with sulphuric acid (5 ml 12M H_2SO_4 for 1 h at 35 °C and, after adding 25 ml water, 1 h at 100 °C). The neutral sugars released on hydrolysis were measured as alditol acetates by gas chromatography or colorimetric measurement, and the uronic acids by colorimetry. After the sulphuric acid stage the hydrolysate was neutralized with sodium hydroxide, dinitrosalicylate reagent was added and the mixture heated for 15 min at 100 °C and absorbances for test samples and a standard sugar mixture read at 530 nm. An estimation of the insoluble NSP present in a sample was obtained by replacing the precipitation of soluble NSP with ethyl alcohol by extraction with 40 ml 0.2 M sodium phosphate buffer (pH 7) for 30 min at 100 °C. The values obtained represent insoluble NSP; soluble NSP is given by the difference between total NSP and insoluble NSP. In the procedure for total NSP, cellulose was dispersed with 12 M sulphuric acid prior to hydrolysis. When this dispersion was omitted from the procedure and replaced by direct hydrolysis with 30 ml 2 M H_2SO_4 for 1 h at 100 °C, cellulose was not measured, and a value for non-cellulose polysaccharides (NCP) was obtained. A value for cellulose was calculated as the difference between the glucose content of total NSP and that of the NCP obtained either by gas chromatography of individual sugars or by a specific colorimetric method using glucose-oxidase [21, 22].

Neutral sugars. Neutral sugars were derived from the cooled hydrolysate to alditol acetates by reduction, and acetylation [22], using 0.5 ml of an internal standard (a concentration of 25 mg myo-inositol/25 ml 1 M H_2SO_4) and N-methylimidazole as the catalyst during acetylation (prepared alditol acetates are stable for at least 1 week at 5 °C). Capillary chromatography was performed on a Hewlett-Packard 568O GC system with an SP-2330 wide-bore capillary column (30 m × 0.75 mm) and a flame ionization detector (FID), and a 3393A HP integrator. The injector temperature was 275 °C, the detector temperature was 285 °C, the column temperature was held at 220 °C, the carrier gas (He) flow rate was 7–8 ml/min, the carrier make-up gas (N_2) flow rate was 60 ml/min, and splitter vent flow was 60–70 ml/min; the injection quantity was 1 μl.

Uronic acids. Uronic acids were determined colorimetrically, using glucuronic acid as the standard [22]. The hydrolysate (0.3 ml) was mixed, diluted (1:5) with 2 M H_2SO_4, with 0.3 ml of sodium chloride-boric acid solution [2 g sodium chloride and 3 g boric acid (H_3BO_3) in 100 ml water]. Concentrated sulphuric acid (5 ml) was added and the solution vortex mixed, placed in a heating block at 70 °C, and left for 40 min, then cooled to room temperature in ice-water. Then 0.2 ml of 3,5-dimethylphenol solution (0.1 g in 100 ml glacial acetic acid was added), and vortex mixed immediately. Between 10 and 15 min later, the absorbance was read at 400 nm and 450 nm against a water reference. The reading at 400 nm was subtracted from that at 450 nm, to correct for the interference from hexoses. The difference in absorbance obtained was plotted against glucuronic acid standards (Fluka, Buchs, Switzerland) over the range 25, 50, 75, 100 and 125 μg/ml. Sample concentrations were calculated, or read from the graph.

Detergent fibres and Klason lignin. Acid-detergent fibre (ADF) was determined according to Van Soest [23]. A 1 g sample was hydrolysed with 0.5 M H_2SO_4 for 1 h at 100 °C. After filtration, the residue was washed with water, acetone, and petroleum ether

and then dried and weighed. A correction was made for the amount of ash in the residue, and the amount of ADF was calculated. Neutral-detergent fibre (NDF) was determined according to Van Soest and Wine [24] with the modification of Mongeau and Brassard [25]. The 1 g sample was boiled in water for 1 min at 100 °C to gelatinize the starch. After cooling, the starch in the sample was hydrolysed with a-amylase (Sigma, St. Louis, Mo.) and treated for 1 h at 100 °C with an NDF reagent of pH 7 (30 g sodium lauryl sulphate, 18.612 g sodium hydrogen-EDTA, 6.81 g sodium tetraborate, 4.56 g disodium hydrogen phosphate, and 10 ml 2-ethoxyethanol in 800 ml distilled water) in the Tecator Fibertec System M (1020 Hot Extractor; Tecator AB, Höganäs, Sweden). After filtration, the residue was washed with hot water, acetone, and petroleum ether and then dried and weighed. A correction was made for the amount of ash in the residue, and the amount of NDF was calculated. The loss of weight gives the cellulose and lignin quantity in the sample, fundamental components of crude fibre. Klason lignin or "sulphuric lignin" (LAD) is the residue, insoluble in 72% sulphuric acid. It was determined gravimetrically as ash-free acid-insoluble residue. The acid detergent residue was treated with 72% sulphuric acid to separate cellulose from cutin. The crucible was placed in an enamel pan and half-filled with 72% sulphuric acid. Glass rods were used to stir and melt all particles. Asbestos was not used. The crucible was continously replenished with sulphuric acid which was then removed by suction and the residue thoroughly washed with hot distilled water. The crucible was then dried overnight at 100 °C and weighed hot. Further loss of weight upon ashing (4 h at 525 °C) was interpreted as loss of Klason lignin.

Crude fibre. The method of crude fibre determination [20] was sequential extraction of 1 g cocoa husk with dilute acid (1.25% H_2SO_4) and alkalí (1.25% NaOH), and isolation of the insoluble residue by filtration.

Starch. The starch content was determined enzymatically by the Boehringer test kit method (Mannheim). About 0.5 g of fat-free cocoa husk was weighed. The starch was dissolved using 20 ml dimethylsulphoxide and 5 ml of 37% hydrochloric acid, and incubating at 60 °C for 30 min. The pH was adjusted to between 4 and 5 in a 100 ml volumetric flask, made up to volume with double-distilled water, and 0.1 ml of the solution used to carry out the analysis.

Water-holding capacity. Approximately 20 ml water was added to a 30 ml centrifuge tube containing 0.8–1.0 g NDF. This was mixed using a glass rod and shaken for 1 h in a water bath at 37 °C, leaving the glass rod in the tube for better mixing. After centrifuging at 14 000 *g* for 1 h at 10 °C, the supernatant was discarded and the tube drained for 15 min. The wet NDF was weighed, dried overnight at 18–20 °C, and weighed again to determine the water content [26]. The water-holding capacity (WHC) was expressed in grams of water held by 1 g cocoa husk.

Statistical analyses. ANOVA and Duncan's multiple range test were carried out using the Statgraphics Statistical package, version 6.0 [27]. Group differences were considered statistically significant at a level of $P \leq 0.05$. All determinations were carried out in triplicate.

Results and discussion

It is important that samples are ground or homogenized to a small and consistent size prior to analysis, and the type of mill used in this study is recommended. Table 2 shows the results of the determination of the composition of cocoa husk. Fat is the main fraction in cocoa beans (50–55 g/100 g), whereas it is a minor component of cocoa husk (<3 g/100 g). The distribution between IDF and SDF is indicated. The data from the Englyst procedure were compared with those obtained from the detergent procedure. In the method described, the

Table 2 Chemical composition of cocoa husk (g/100 g). *WHC* Water holding capacity (g H_2O/g), *NSP* non-starch polysaccharides, *IDF* insoluble dietary fibre, *SDF* soluble dietary fibre, *NCP* non-cellulosic polysaccharides, *ADF* acid detergent fibre, *NDF* neutral detergent fibre

Parameter	Sample no.												$\bar{x}$	SD	V_{max}	V_{min}
	1	2	3	4	5	6	7	8	9	10	11	12				
Water content	6.3	7.4	6.9	7.0	7.1	7.6	6.6	7.3	7.8	7.7	5.3	3.6	6.72	1.2	7.8	3.6
Crude protein	15.5	13.9	14.2	12.8	15.3	14.8	15.2	15.8	15.8	12.5	17.6	16.1	15.0	1.43	17.6	12.5
Ash	11.6	10.5	11.9	9.8	9.3	10.2	10.8	10.9	11.4	12.0	10.7	9.7	10.7	0.88	12.0	9.3
Fat	2.5	2.2	2.3	2.3	2.4	2.2	2.3	2.3	2.2	1.8	2.3	3.0	2.32	0.27	3.0	1.8
WHC	3.87	3.72	4.12	2.8	2.98	3.26	3.68	4.04	3.86	4.18	3.29	3.66	3.62	0.47	4.18	2.8
NSP	44.5	41.8	43.2	45.0	43.6	44.2	43.2	39.9	43.8	49.4	43.3	44.3	43.8	2.32	49.4	39.9
IDF	30.6	27.3	27.2	27.6	28.6	30.0	28.5	24.2	26.7	30.8	30.2	28.6	28.3	2.0	30.8	24.2
SDF	14.9	14.5	16.0	17.4	15.0	14.2	14.7	15.7	17.1	18.6	13.1	15.7	15.6	1.6	18.6	13.1
Cellulose	21.4	20.3	19.6	17.5	20.2	20.1	20.3	17.0	18.3	20.8	21.3	19.5	19.7	1.48	21.4	17.0
NCP[a]	6.7	3.7	7.5	9.5	5.5	4.1	6.0	5.7	5.6	8.9	3.9	5.4	6.1	1.93	9.5	3.7
NCP[b]	6.4	4.0	5.5	6.9	4.7	5.2	5.3	4.6	5.0	6.7	4.6	5.6	5.35	0.94	6.9	4.0
NCP[c]	13.1	7.7	13.0	16.4	10.2	9.3	11.3	10.3	10.6	15.6	8.5	11.0	11.5	2.79	16.4	7.7
Uronic acid[a]	8.0	10.5	8.8	7.7	9.2	9.8	8.4	9.7	11.0	9.5	9.9	10.0	9.32	1.02	11.0	7.7
Uronic acid[b]	2.7	2.9	2.1	3.1	3.6	4.7	2.9	2.8	3.2	2.9	3.2	3.4	3.1	0.65	4.7	2.1
Uronic acid[c]	10.7	13.4	10.9	10.8	12.8	14.5	11.3	12.5	14.2	12.4	13.4	13.4	12.4	1.35	14.5	10.7
Starch	1.1	1.3	1.07	0.95	1.4	1.2	0.85	0.97	1.1	1.2	1.3	1.18	1.13	0.17	1.4	0.85
CF	21.6	20.3	21.2	16.5	18.5	20.7	18.1	18.8	19.2	20.6	19.7	19.4	19.6	1.52	21.6	16.5
LAD	13.5	13.1	12.2	16.1	17.0	13.2	15.7	11.5	12.0	13.8	12.5	13.3	13.7	1.81	17.0	11.5
ADF	31.7	32.0	28.4	27.1	25.4	24.8	34.9	22.3	28.7	25.9	29.8	30.0	28.3	3.69	34.9	22.3
NDF	47.2	45.4	50.3	34.2	36.3	39.7	44.9	49.3	47.1	51.0	40.1	44.6	44.1	5.73	51.0	34.2

[a] In SDF
[b] In IDF
[c] Total NCP

Table 3 Neutral sugars and uronic acids (g/100 g)

Parameter	Sample no.												$\bar{x}$	SD	V_{max}	V_{min}
	1	2	3	4	5	6	7	8	9	10	11	12				
Glucose	16.3	16.2	15.7	14.0	16.2	16.4	16.2	13.6	15.1	16.7	16.3	15.6	15.7	1.03	16.7	13.6
Arabinose	9.8	5.8	9.8	12.3	7.7	7.0	8.5	7.7	8.5	11.7	7.2	8.5	8.7	2.0	12.3	5.8
Galactose	4.1	4.0	3.9	3.5	4.0	4.2	4.1	3.4	3.9	4.2	4.1	3.9	3.9	0.27	4.2	3.4
Xylose	2.4	1.4	2.3	3.0	1.8	1.7	2.0	1.9	1.9	2.8	1.7	2.0	2.08	0.49	3.0	1.4
Rhamnose	0.9	0.5	0.9	1.1	0.7	0.7	0.8	0.7	0.7	1.0	0.7	0.8	0.79	0.17	1.1	0.5
Total sugars	33.5	27.9	32.6	33.9	30.4	30.0	31.6	27.3	30.1	36.5	30.0	30.6	31.3	2.71	36.5	27.3
Uronic acids	10.7	13.4	10.9	10.8	12.8	14.5	11.3	12.5	14.2	12.4	13.1	13.4	12.4	1.35	14.5	10.7
Total NSP	44.2	41.3	43.5	44.7	43.2	44.5	42.9	39.8	44.3	48.9	43.1	44.0	43.7	2.27	48.9	39.8

fractionation technique from a gas chromatography procedure was combined with colorimetric measurement of reducing sugars (Table 3). The results show a high NSP content in cocoa husk of 43.8 ± 2.32 g/100 g consisting of 28.34 g/100 g IDF and 15.6 g/100 g SDF (Table 2). The value of fibre (NSP plus LAD) was 57.5 g/100 g. The most indigestible fraction of the dietary fibre, ADF, is basically cellulose, lignin and cutin, with an average content of 28.3 ± 3.69 g/100 g in cocoa husk. A separate analysis of each component of the fraction gave a content greater than that detected with the detergent method ($\bar{x} = 34.7$ g/100 g). The NDF takes into account the vegetal cell wall components, mainly cellulose, lignin, and hemicellulose (HMC), giving an average content of 44.10 ± 5.73 g/100 g. In this fraction the addition of the individually analysed contents of lignin, cellulose and hemicellulose gives a percentage similar to that obtained with the detergent method ($\bar{x} = 44.9$ g/100 g) (Table 2). The contents of NSP, NDF, ADF, cellulose, crude fibre (CF), HMC, and Klason lignin (LAD) in cocoa husk were compared with other fibre sources. All values exceed the fibre content of cereal bran, and are found within the range of the products basically used as a source of dietary fibre [Arbran soy fibre 60 g/100 g; Arbran wheat bran, 44 g/100 g; Nutrifibre rice fibre 25 g/100 g; Prune fibre 7 g/100 g (Archer Daniels Midland Co 1992)]. The high value of dietary fibre content obtained in this study is in agreement with the reports of various authors concerning the fibrous nature of the husk [17, 28]. The quality of the fibre depends on the insoluble/soluble fibre ratio, and on the non-nutritional elements found [29]. Excluding the lignin, the soluble fibre represents approximately 35.5% of the total NSP (15.6 ± 1.6 g/100 g). The elevated fibre content and the ratio between insoluble and soluble fibre (IDF/SDF = 1.82) found in the cocoa husk justifies its inclusion as a nutritional product. It is generally believed that the importance of pectic substances in plants is the role they play during the development of the cell wall. The data in this paper demonstrate that galacturonic acid is found in SDF ($\bar{x} = 9.32 \pm 1.02$ g/100 g) and IDF ($\bar{x} = 3.10 \pm 0.65$ g/100 g). The total galacturonic acid content is in agreement with Adomako [19]. The starch content is similar in the samples of cocoa husk at $\bar{x} = 1.13 \pm 0.17$ g/100 g (Table 2). Considering the structural classification of polysaccharides [30], the presence of cellulose, hemicellulose (xylans) and pectic substances (arabinans and galactans) as major constituents can be deduced from this composition and from the appreciable content of uronic acids. The polysaccharides cellulose and HMC are abundant in the insoluble fraction of the cocoa husk. Cellulose ($\bar{x} = 19.70 \pm 1.48$ g/100 g) is its main constituent, followed by HMC ($\bar{x} = 5.35 \pm 0.94$ g/100 g) and galacturonic acid ($\bar{x} = 3.10 \pm 0.65$ g/100 g) (Table 2). From these results it can be concluded that the addition of cocoa husk to food products can: (1) increment the content of dietary fibre; (2) improve the ratio IDF/SDF, (3) reduce the calories contributed, (4) lower the percentage of phytic acid supplied by cereal bran [31]. To improve the IDF/SDF ratio, fibres of other origins were extracted, grouped and classified according to the following criteria: (1) equilibrated fibre (more than 30% soluble fibre); (2) of high fibre content (>40 g/100 g), (3) higher equilibrated fibre (>50% soluble fibre), (4) high content of soluble fibre (>20 g/100 g), (5) high LAD content and (6) high content of condensed tannins and polyphenols [32]. Cocoa husk can be included in types (1), (2), (5), and (6). No significant differences ($P \leq 0.05$) were noted in total dietary fibre, SDF or IDF, between samples and provinces.

To complete the study, cocoa husk was analysed for ADF, NDF, raw fibre and LAD contents (Table 2). Since the contents of cellulose and CF in cocoa husk are similar, the total CF can be considered to be largely cellulose ($\bar{x} = 19.60 \pm 1.52$ g/100 g). The total CF was also estimated using the formula % CF = 0.77 × % ADF-0.49 [33]. According to the results obtained, analytical and calculated values were of similar proportions. The results in Table 2 also show that the NCP forms one of the main fractions of the cocoa husk ($\bar{x} = 11.5 \pm 2.79$ g/100 g), whose components are found distributed between SDF ($\bar{x} = 6.10$ g/100 g) and IDF ($\bar{x} = 5.35$ g/100 g). The ratio cellulose (C)/HMC was found to differ between the cocoa husk (C/HMC < 2.06), and the cereal brans (C/HMC > 2) [25–26, 34]. Lignin values varied significantly among the fibre sources, being lowest in soy bran, sugar beet fibre, and barley fibre (less than 5 g/100 g lignin) and highest in Dupro and Centara pea fibres, and bleached oat fibre

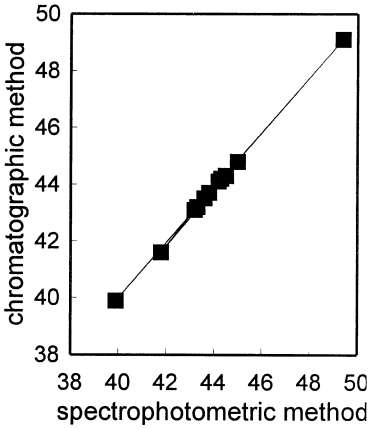

Fig. 1 Correlation between results of the chromatographic and spectrophotometric methods in non-starch polysaccharide

(>50 g/100 g lignin) [35]. The average content in cocoa husk was 13.7 ± 1.81 g/100 g (Table 2) [36]. The composition of cocoa husk and cocoa beans was compared. Valiente et al. [37] found LAD values of 16.1 ± 0.5 g/100 g roasted cocoa beans, and concluded that total dietary fibre in cocoa beans seemed to be insensitive to roasting. However, the largest change in constituents was the sharp increase of lignin in IDF. Glucose, arabinose, galactose, rhamnose, and xylose were identified in the neutral sugars fraction, but the glucose and arabinose predominate. The results of the individual analyses are shown in Table 3. Correlating results of dietary fibre using spectrophotometry with those using chromatography, a coefficient of $r^2 = 0.98$ was obtained in Fig. 1 ($y = 0.97x + 1.266$; x colorimetric procedure, y GC procedure) [21].

Depending on the method used, differing WHC values have been reported in the literature. WHC varies from 2.08 g water/g for peanut fibre to 10.85 g water/g for sugar beet fibre [38, 39]. The chemical composition of fibre plays a role in its ability to hold water. Cellulose and lignin tend to have low WHC values, while HMC and pectin have high WHC values. The moderate WHC values found in cocoa husk (3.62 ± 0.47 g water/g) appear to be related to their high concentration of cellulose.

References

1. Cummings JH (1980) Some aspects of dietary fibre metabolism in the human gut. In: Birch GG, Parker KS (eds) Dietary fibre. Applied Science, London, pp 442–458
2. Fisher N, Berry CS, Fearn T, Gregory JA, Hardy J (1985) Am J Clin Nutr 42:788–804
3. National Research Council (1989) Recommended dietary allowances, 10th edn. National Academy Press, Washington, DC
4. James WPT, Theander O (eds) (1981) The analysis of dietary fibre in foods. Dekker, New York
5. Lichon MJ, James KW (1996) J Assoc Off Anal Chem Int 79:54–61
6. Bravo L, Abia R, Saura Calixto F (1994) J Agric Food Chem 42:1481–1487
7. Serra Bonvehí J, Ventura Coll F (1997) Z Lebensm Unters Forsch A 204:287–292
8. Serra Bonvehí J, Ventura Coll F (1997) Food Chem 60:365–370
9. Selvendran RR, Stevens BJH, Du Pont MS (1987) Adv Food Res 31:117–209
10. Slavin J (1991) J Am Diet Assoc 91:816–819
11. Guillén R, Sánchez C, Jiménez A, Heredia A (1995) Z Lebensm Unters Forsch 200:225–228
12. Unten S, Ushiyima H, Shimizu H, Tsuchie H, Kitamura T, Moritome N, Sakagami H (1991) Lett Appl Microbiol 14:251–254
13. Abbiola SS, Tewe OO (1991) Trop Agric (Trinidad) 68:335–336
14. Devendra C (1980) The feeding value by-products from cocoa acid and coconuts in diets of farm livestock. Proceedings of the International Conference on Cocoa and Coconuts. Incorporated Society of Planters, Kuala Lumpur, pp 457–471
15. Lopez AS, Ferreira HIS, LLamosas AC, Pinheiro RA (1984) Rev Theobroma 14:271–291
16. Francis Lopes SA, Santana Ferreira HI, Llamosas AC, Pinheiro Romeu A (1985) Situaçáo atual da utilizaçao de suproductos de cacau no Brazil. CEPLAC Boletín Técnico no. 133, Itabuna, Bahia, Brazil
17. Martín Cabrejas MA, Valiente C, Esteban RM, Mollá E, Waldron K (1994) J Sci Food Agric 66:307–311
18. Adomako D (1972) Phytochemistry 11:1145–1148
19. Adomako D (1977) Recent development in cocoa by-products research in Ghana. 6th International Cocoa Research Conference, Caracas, 1977. Actas Lagos, Nigeria, Cocoa Producer's Alliance (ed), pp 706–718
20. AOAC (1995) Official methods of analysis, 16th edn. Association of Official Analytical Chemists, Arlington, Va.
21. Englyst HN, Hudson GJ (1987) Food Chem 24:63–76
22. Englyst HN, Quigley ME, Hudson GS, Cummings JH (1992) Analyst 117:1705–1714
23. Van Soest PJ (1963) J Assoc Off Agric Chem 46:829–835
24. Van Soest PJ, Wine RH (1967) J Assoc Off Anal Chem 50:50–55
25. Mongeau R, Brassard R (1982) J Food Sci 47:550–555
26. Mongeau R, Brassard R (1982) Cereal Chem 59:413–417
27. SAS (1990) User's guide: statistics, version 6, 4th edn. SAS Institute, Cary, NC
28. Anon (1987) Cereal Food World (Dietary Fiber Update) 32:355–365
29. Marlett JA (1992) J Am Diet Assoc 92:175–186
30. Aspinall GO (1980) Carbohydrate: structure and function. In: Preiss J (ed) The biochemistry of plants. Academic Press, New York, pp 36–78
31. Serra Bonvehí J, Ventura Coll F (1997) Acta Aliment 26:243–253
32. Saura Calixto F (1990) Aliment Equipos Tecnol 3:171–175
33. Jones NE (1994) J Assoc Off Anal Chem Int 77:1684–1685
34. Ranhotra GS, Galroth JA, Astroth K, Posner ES (1990) J Food Sci 55:1349–1351
35. Idouraine A, Hassani BZ, Claye SS, Weber CW (1995) J Agric Food Chem 43:1580–1584
36. Saura Calixto F (1988) J Food Sci 53:1769–1771
37. Valiente C, Esteban RM, Molla E, López Andreu FJ (1994) J Food Sci 59:123–124
38. Frölich W (1984) Bioavailability of minerals from unrefined cereals products. In vitro and in vivo studies. University of Lund, Sweden, p 150
39. Weber CW, Kohlhepp EA, Idouraine A, Ochoa LJ (1993) J Agric Food Chem 41:1931–1935