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THE DIGESTIBLE CARBOHYDRATE AND DIETARY FIBRE CONTENTS OF COMMON SRI LANKAN PLANT FOODSTUFFS

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Abstract: The dietary fibre and digestible carbohydrate contents of over 50 typically Sri Lankan plant food sources is reported. Digestible carbohydrate was determined by specifically hydrolysing carbohydrate enzymatically (heat stable α- amylase, amyloglucosidase and invertase) followed by determining reducing sugar formed colorimetrically. As expected, this gives lower values than carbohydrate determined "by difference" as reported by the food composition tables of the region. This in turn lowers the true energy value of the food. The over-estimation was maximum (5-12 fold) in case of leafy vegetables and minimum in case of starchy tubers(< 1.15 fold) and cereals and pulses(<1.2 fold). The digestible carbohydrate values were over-estimated by 1.5 fold in case of non-starchy tubers and fruits. In the case of fruit vegetables the variation in over-estimation was high. (1 - 5 fold). Dietary fibre has been quantified using an enzymic digestion process of Asp and co-workers followed by gravimetry. This has resulted in the determination of both soluble and insoluble dietary fibre which would be vitally important to nutritionists, physicians and the public, if incorporated into Sri Lankan food composition tables.

Key words: Digestible carbohydrate, Soluble and insoluble dietary fibre, Sri Lankan plant foodstuffs.

INTRODUCTION

Carbohydrates, especially in plant derived food, are becoming increasingly important. What was termed undigested "carbohydrates" included a plethora of chemical types primarily but not exclusively from plant cell walls, e.g. cellulose, hemicellulose, lignin, modified starches, pectin, oligosaccharides, glycoproteins, cutin, waxes, phenolic esters, etc.

From the viewpoint of biochemical activity, these carbohydrates and allied components are best termed dietary fibre (DF)[2], which in turn is classified into soluble dietary fibre (SDF) and insoluble dietary fibre (IDF).[2] Dietary fibre was initially defined as the 'skeletal remains of plant cell walls, in our diets, that are resistant to hydrolysis by the digestive enzymes of humans.' As this definition did not include the polysaccharides present in some food additives, the definition was later extended to include 'all the polysaccharides and lignin in the diet that are not digested by the endogenous secretions of the human digestive tract'. Accordingly, for analytical purposes, the term dietary fibre refers mainly to the non starch

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polysaccharides (NSP) and lignin in the diet.[3] At the outset it should be stated that the assumption that fibre is not energy generating is not quite accurate as a small amount of the calorific potential of dietary fibre is utilized with the aid of gut microflora via the enterohepatic circulation.[4] The two types of dietary fibre, SDF and IDF have different chemical identities and have different biochemical effects in the gut. Therefore their separate quantification is important. This study will result in an improvement of the values contained in the food composition tables of India[5] (which gives only crude fibre) and Sri Lanka[6] (which does not give any value for dietary fibre).

To summarize, the far reaching nutritive effects of dietary fibre lowers glycaemic index by en-meshing glucose in the DF matrix thus decreasing the rate of hydrolysis. Dietary fibre adsorbs bile acids and bile salts and consequently lowers the plasma cholesterol levels by using plasma cholesterol to maintain the bile salt pool. Acetate and propionate formed from SDF inhibits the key cholesterol synthesising enzyme(HMG CoA reductase) as well.[4] Dietary fibre absorbs toxins. It also absorbs water to increase stool bulk and lower the incidence of large bowel diseases.[7]

Most food composition tables list carbohydrate percentage by 'difference'. This means that all the macro-constituents of food are first determined eg. protein, fat, minerals and moisture. These are added and the sum substracted from 100. This gives a high value especially in the calculation of the energy value of food as carbohydrate calculated in this way will contain non-digestible carbohydrate as well as non-carbohydrate components of no biological energy value.[7]

In this study we directly determined digestible carbohydrates i.e. those that can be hydrolysed by human digestive enzymes by using α–amylase (α-1,4 bonds), amyloglucosidase (α-1,6 & α-1,4 bonds) of α-1,4 glucanoglucans including starch. Invertase was used for sucrose hydrolysis. Analysis of reducing sugar will give directly digestible carbohydrate.

The objective of this study is to (I) determine the clinically significant SDF and IDF content and (II) determine any significant inaccuracies in the estimation of digestible carbohydrate in selected Sri Lankan foods.

METHODS & MATERIALS

Plant Food Samples: Samples 250 to 500g (3 from each food) were purchased at different times from retail outlets in Nugegoda and Maharagama or collected from home gardens from May-Dec (1998), Nov- Dec (1999) and Feb-March (2000). The dry foods were stored at ambient temperatures at <10% moisture for use. High moisture foods were either dried in an oven at 105^{0}C to constant weight or blended in a domestic Sumeet blender for direct use.

Moisture contents of the blended samples were determined by the Dean & Stark method.[8]

Dietary Fibre: This was analyzed by the method of Asp and co-workers[9] on the powdered or blended material. The sample was suspended in pH 6 phosphate buffer (20 ml) and termamyl (400 µl) was added and the suspension was heated in a boiling water bath (90-100^0 C) for 20-30 minutes. Distilled water (20 ml) was added, pH adjusted to 1.5 by the addition of HCl (5M) and digested by pepsin (100 mg) for 1hour at 40^0 C. The pH adjusted to 6.8 with NaOH (5M) . Pancreatin (100mg) added and incubated for another hour at 40^{0}C in a shaking water bath. The pH re-adjusted to 4.5 with HCl (1M) and the sample filtered through a dry and weighed crucible containing the filter aid kieselguhr (0.5g). The residue was washed with distilled water and the washings were added to the filtrate until the volume of filtrate was 100 ml. The residue contains IDF. The volume of filtrate was made to 500 ml with the addition of methanol (95%) so that final concentration of methanol was 78%. This solution was warmed to 60^0 C and kept for 1 hour for SDF precipitation. The temperature was brought down to room temperature and contents kept in an ice bath (5min) before filtering through a dried and weighed crucible containing kieselguhr. Both IDF and SDF residues were washed with acetone and dried at 105^{0}C to constant weight and then incinerated at 550^0 C for 5 hours and weighed again after keeping in a desiccator.

The principle of the method is to solubilise (digest) all digestible matter with pepsin, pancreatin and termamyl and determine the insoluble residue, gravimetrically. This is followed by precipitating the soluble fibre, from the filtrate, using the fact that it is insoluble in 78% alcoholic medium at 60^{0}C. Analyses were done in duplicate.

Digestible Carbohydrate: A sample containing approximately 1g starch in 100ml was enzymatically digested by a method modified from Holm & co-workers[10] using excess termamyl (ex-Novo) from *Bacillus licheniformis* (100 units) at pH 6.0 and 90-100^{0}C for 1 hour, cooled to 37^{0}C. Invertase from *Candida utilis* species (40 units) was added and the mixture incubated for 3 hours at 37^{0}C, followed by incubation at pH 4.5 and 55^{0}C with amyloglucosidase ex- Novo (1000 units) containing pullulanase. In all experiments a control of 1g maize starch was run under identical conditions to confirm that hydrolytic conditions were ideal.

The reducing sugars formed were determined by the colorimetric methods of Nelson[11] or Miller[12] using an ELICO SL 150 UV/VIS spectrophotometer at 580 nm and 550 nm respectively to measure colour. The regression values for the standard curves were 0.990 and 0.999 respectively and coefficient of variation at mid point of the standard curve 5% and 2% respectively. However, the standard curves were used only to confirm linearity, while the standard starch hydrolysate readings were used to compute results.

RESULTS

Results are shown in tables 1 to 8. The results are a mean of 3 different samples in each case with each sample done in duplicate. In most cases the deviations are small. One major exception is seen in the case of cowpea (Table 3).

Table 1: Digestible carbohydrate and dietary fibre levels of leafy vegetables on dry basis.

Type	Carbohydrate by difference (X) (%)	Digestible Carbohydrate (Y) (%)	Overestimation of directly digestible Carbohydrates (X)-(Y)	Fibre Content %	
				IDF	SDF
Ipomoea aquatica (Kankun)	32.0	6.8	25.2	58.8	2.7
Sesbania grandiflora (Katurumurunga)	53.9	7.5	46.4	58.8	4.2
Alternanthera sessilis (Mukunuwenna)	43.1	3.6	39.5	44.8	10.8
Lasia spinosa (Kohila)	Not given	10.1	-	51.8	2.5
Centella asiatica (Gotukola)	40.7	12.4	28.3	56.2	8.7
Brassica oleracea (Cabbage)	55.3	22.1	33.2	35.2	4.7
Murraya koenigii (Karapincha) Curry leaves	Not given	3.5	-	62.3	14.1
Spinacia oleracea (Spinach)	34.5	11.7	22.5	38.8	8.7
Allium porrum (Leeks)	72.9	29.2	43.7	58.2	1.8

X = From Sri Lankan Food composition table
Y = Digestible carbohydrate values are given as mean of duplicates
* Determined by DNS method

Table 2: Digestible Carbohydrate and dietary fibre levels of cereals on dry basis.

Type	Carbohydrate by difference (X) (%)	Digestible Carbohydrate (Y) (%)	Overestimation of Directly digestible Carbohydrates (X)-(Y)	Fibre Content %	
				IDF	SDF
Raw white rice	90.6	85.3	5.3	2.9	1.3
Raw red rice	88.5	85.1	3.4	4.4	1.1
Parboiled white rice	91.1	82.4	8.7	3.9	2.2
Parboiled red rice	88.6	82.0	6.6	4.9	2.1
Refined wheat flour	85.2	83.4	11.8	2.7	0.9
Whole wheat flour	79.1	76.2	2.8	10.4	1.3

See table 1 for foot notes
Rice = *Oryza sativa*
Wheat = *Triticum aestivum*

Table 3: Digestible Carbohydrate and dietary fibre levels of pulses on dry basis.

Type	Carbohydrate by difference (X) (%)	Digestible Carbohydrate (Y) (%)	Overestimation of Directly digestible Carbohydrates (X)-(Y)	Fibre Content %	
				IDF	SDF
Cowpea	62.9	19.1	-	20.3	14.0
(*Vigna sinensis*)	-	57.9	-	10.3	1.6
	-	36.8	-	13.8	4.1
Green gram	63.3	55.3	7.9	11.8	15.2
(*Phaseolus aureus*)					
Red dhal	66.5	63.2	3.3	5.3	2.6
(*Lens esculenta*)					
Toor dhal	66.4	66.5	0	4.1	1.9
(*Cajanus cajan*)					

See Table 1 for foot notes

Digestible Carbohydrate

In most foodstuffs there is an overestimation of carbohydrate in food composition tables and as a result an overestimation of directly utilizable energy. Table 9 gives the summarized results.

Table 4 : Digestible carbohydrate and dietary fibre levels of some common fruits on dry basis.

Type	Carbohydrate by difference (X) (%)	Digestible Carbohydrate (Y) (%)	Overestimation of Directly digestible Carbohydrates (X) - (Y)	Fibre Content % IDF	SDF
Sini Banana *Musa sp.*	91.0	81.9	9.1	11.1	1.7
Aanamalu *Musa sp.*	-	79.3	11.5	9.9	3.1
Ambul *Musa sp.*	-	71.9	19.1	15.2	2.8
Red Plantain *Musa sp.*	-	71.1	19.9	12.2	2.0
Kolikuttu *Musa sp.*	-	68.2	22.8	14.3	2.4
Jak fruit *Artocarpus heterophyllus*	85.2	87.3	* Higher value for Y	4.8	2.9
Papaya *Carica papaya*	78.3	69.4	8.9	15.3	8.4
Apple** *Malus sylvestris*	87.0	67.1	19.9	11.5	7.1
Pineapple *Ananas comosus*	88.5	61.0	27.5	7.8	2.8
Mango *Mangifera indica*	88.9	55.7	33.2	21.9	4.8
Orange *Citrus aurantium*	87.9	51.5	36.4	14.5	6.9
Wood apple *Limonia acidissima*	47.5	29.5	17.9	55.3	6.5
Guava *Psidium guajava*	61.2	21.4	39.8	61.0	7.4
Avocado *Persea americana*	3.1	3.7	* Higher value for Y	7.5	3.2

* Could be varietal
** For comparison
See table 1 for foot notes

Table 5 : Digestible carbohydrate and dietary fibre levels of fruit vegetables on dry basis.

Type	Carbohydrate By difference (X) (%)	Digestible Carbohydrate (Y) (%)	Overestimation of Directly digestible Carbohydrates (X) - (Y)	Fibre Content %	
				IDF	SDF
Bitter gourd *Momordica charantia*	55.3	12.4	42.9	59.7	6.6
Capsicum *Capsicum annuum var. gross*	42.6	22.8	19.8	34.9	7.0
Green chillies *Capsicum annuum*	21.0	23.0	* Higher value for Y	55.9	4.6
Dambala *Psophocarpus tetragonolobus*	Not given	11.0	-	48.8	12.3
Drumsticks *Moringa oleifera*	28.3	24.3	4.0	47.5	8.6
Green beans *Phaseolus vulgaris*	71.5	26.0	45.5	27.8	4.6
Ladies fingers *Hibiscus esculentus*	61.5	26.5	35.0	38.2	3.4
Brinjals *Solanum melongena*	54.8	23.5	31.3	38.7	3.9
Snake gourd *Trichosanthes cucumerina*	61.1	33.8	27.3	17.2	7.9
Pumpkin *Cucurbita maxima*	62.2	33.8	28.4	24.2	8.4
Tomato *Lycopersicon esculentum*	60	44.36	15.79	18.1	5.2
Ridged gourd *Luffa acutangula*	70.8	45.5	25.4	24.4	12.1
Kathurumurunga flower *Sesbania grandiflora*		36.1 Not given	-	32.4	5.4
Cucumber *Cucumis sativus*	67.6	47.3	20.3	13.2	5.7
Raw Amberalla *Spondias pinnata*	94.6	53.7	40.9	17.3	7.5
Ash plantain *Musa sapientum*	83.3	71.8	11.5	13.0	4.1
Breadfruit *Artocarpus incisus*	77.1	68.0	9.1	14.6	4.3

See table 1 for footnotes

Table 6: Digestible carbohydrate levels of non starchy tubers on dry basis.

Type	Carbohydrate by difference (X) (%)	Digestible Carbohydrate (Y) (%)	Overestimation of Directly digestible Carbohydrates (X) - (Y)	Fibre Content %	
				IDF	SDF
Carrot *Daucus carota*	75.7	55.6	20.1	20.3	5.0
Beet root *Beta vulgaris*	71.6	58.0	13.1	18.8	4.3
Radish *Raphanus sativus*	60.7	33.4	27.3	27.2	7.2
Kohila *Lasia spinosa*	Not given	25.3	-	39.6	5.2
Onions (Big) *Allium cepa*	84.7	35.3	49.4	10.3	10.1

See table 1 for footnotes
* By DNS method

Table 7 : Digestible carbohydrate levels of starchy tubers on dry basis.

Type	Carbohydrate by difference (X) (%)	Digestible Carbohydrate (Y) (%)	Overestimation of Directly digestible Carbohydrates (X) - (Y)	Fibre Content %	
				IDF	SDF
Potato *Solanum tuberosum*	89.3	78.6	10.7	3.2	1.0
Sweet potato *Ipomoea batatas*	89.5	83.2	6.3	5.6	4.3
Manioc *Manihot esculenta*	98.9	87.1	11.8	1.7	3.1

See table 1 for footnotes

Dietary fibre

The values obtained for IDF and SDF are given separately. The total fibre values given for guava and woodapple (Table 4) and bitter gourd and green chillies (Table 5) are suspect as they originate from the seeds which are not edible (food composition tables express results as $g\ .100g^{-1}$ edible). The seeds will not act biologically as fibre.

Table 8 : Digestible carbohydrate levels of miscellaneous foods on dry basis.

Type	Carbohydrate by difference (X) (%)	Digestible Carbohydrate (Y) (%)	Overestimation of Directly digestible Carbohydrates (X) - (Y)	Fibre Content %	
				IDF	SDF
Jak fruit seeds	72.7	48.4	24.3	45.6	3.7
Dessicated coconut	29.5	10.4	19.1	17.0	0.8

See table 1 for foot notes
Jak- *Artocarpus heterophyllus*
Coconut- *Cocos nucifera*

Table 9 : Digestible carbohydrate levels and overestimation in foodstuffs.

Type	Digestible Carbohydrate %	Overestimation	Exceptions	Reasons
Leafy Vegetables	7-12	5-12 fold	Cabbage and Leeks	Not known
Fruit Vegetables	22-47	1-5 fold	<22%=Bitter gourd	Seeds
			>47%=Raw amberella Ash plantain Bread fruit	Reducing sugars Starchy material Starchy material
Non-starchy tubers	32-58	1.5 fold	Kohila yam(25%)	Roughage
Starchy tubers	78-87	<1.2	No exceptions	-
Fruits	55-80	=1.5	<55%= Avocado Woodapple Guava Orange	High oil Seeds Seeds Citric acid
Cereals and Pulses	73-85 and 55-66	<1.2	Cowpea	See text

DISCUSSION

The lowest digestible carbohydrate and highest fibre content was seen in the case of leafy vegetables. This constitutes roughage. Fruit vegetables such as winged beans, bitter gourd, capsicum, drumsticks, green beans, ladies fingers and brinjals gave comparatively lower digestible carbohydrate contents when compared to snakegourd, ash pumpkin, cucumber, tomatoes, raw amberella, ash plantain and breadfruit. The lowest over-estimation was seen in case of breadfruit (1.13 fold) and highest in case of green beans (4.5 fold). Further, it is known that vegetable protein has especially low *in vivo* digestibility e.g. the protein in beans, can have as low a digestibility as 65%. It has also been found that non- protein nitrogen of green beans constitutes 16.2% of total nitrogen.[13] The IDF fraction of green beans may include undigested protein as well.

Interesting results were obtained in the case of cereals. Refined wheat flour which is milled at a 70% extraction rate, had slightly lower digestible carbohydrate values when compared to whole wheat flour, suggesting modification of starch during processing, as drastic conditions like elevated temperature, chlorination etc. prevail during production.

In the case of rice varieties, raw rice had slightly higher digestible carbohydrate than parboiled rice. This could be due to the reason that retrogradation of starch had occurred during the parboiling process resulting in residual starch which is enzymatically inactive. On the other hand, parboiled rice had higher IDF when compared with its raw form. When fibre content was considered, it was observed that red rice had higher IDF when compared with white rice. It is possible that along with the aleurone layer some part of the hull also may be still attached and when milling is carried out to completely remove the aleurone layer, then the resultant polished white rice has less IDF.

As this is an enzymatic assay and as enzymes are specific for substrates, other digestible carbohydrate derivatives such as citric acid cannot be measured. The comparatively large difference seen in case of orange, mango and pineapple may be due to citric acid. The high IDF value in the case of mango may include roughage as well.

From the four varieties of pulses studied, cowpea showed a large variation both in digestible carbohydrate content and dietary fibre content. This may be due to the difference in variety, processing or stage of harvest. It has been reported that pest (*Callosobruchus maculatus*) infestation results in increase of fibre content from 1.9 to 3.3mg /100 g in cowpea. Other than cowpea, green gram seems to be a rich source of fibre. It contains about 15% fibre on a dry basis. Even though the total DF of leafy vegetables, certain fruit vegetables and fruits are high, the low water content of green gram makes it a very rich fibre source on fresh weight basis.

Hydrolytic methods used in this study are enzymatic and therefore specific. It is recommended that chemical methods be used to estimate reducing sugar as we found that many plant extracts inhibit the enzymatic glucose oxidase-peroxidase system. Of the two chemical methods used to determine reducing sugar the 3^1 5^1 dinitrosalicylic acid method[11] is more accurate and reproducible but the Nelson method[12] is more sensitive.

It should be noted that the overestimation of energy may not be as great due to use of an amount of energy (although small) via the enterohepatic circulation as a result of action of gut micro-flora. However this is variable for different foods and cannot be presently estimated. The method also underestimates energy, as it does not include carbohydrate derivatives that are not reducing (e.g. citric acid) which is present in significant amounts in some fruits.

It is felt that these results could be useful additions to the Sri Lankan food composition tables.

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