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Nutritionally important starch fractions in cereal based Indian food preparations

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Abstract

Recent research studies have invalidated the earlier assumptions regarding the rate of digestion of carbohydrates. Hence, in the present study the rate and extent of starch digestion in vitro was measured in 10 cereal-based Indian food preparations (with/without accompaniments). The selected foods included chapathi, dosa, idli, pongal, poori, ragi roti, rice roti, rice flakes upma, semolina idli and upma and the accompaniments — cooked dhal, chutney and potato palya. In view of the nutritional importance of starch, the major starch fractions viz., rapidly digestible starch, slowly digestible starch (SDS) and resistant starch as defined by Englyst [Englyst, H. N., Kingman, S. M., & Cummings, J. H. (1992). Classification and measurement of nutritionally important starch fractions. *European Journal Clinical Nutrition, 46*(2), 333–350] were measured, by using controlled enzymic hydrolysis with pancreatin and amyloglucosidase. In addition, rapidly available glucose (RAG) was measured and a starch digestion index was derived. Dietary fiber components (soluble and insoluble fiber) were measured by the enzymatic method [Asp, N. G., Johansson, C. G., Hallmer, H., & Siljestrom, M. (1983). Rapid enzymatic assay of insoluble and soluble dietary fiber. *Journal of Agricultural Food Chemistry*, 31, 476–482]. The results indicate that the course of starch hydrolysis was not only characteristic for each food but also appears to be affected by the addition of accompaniment. Also, while the correlation between RAG and SDS did not attain significance in foods with accompaniment, a significant inverse correlation ($r = -0.68$, $P < 0.05$) was seen in foods without accompaniment. It is evident that starch digestibility in Indian foods is influenced by the accompaniment rather than the cereal base.

Keywords: Indian foods; Accompaniment; Starch fractions; In vitro digestibility

1. Introduction

Currently food analysis is based on the measurement of chemically distinct components, because such values can be grouped as appropriate when new knowledge of their importance to the consumer becomes available (Englyst & Hudson, 1996; Englyst, Veenstra & Hudson, 1996). It is realized that it is no longer adequate to have only the conventional nutrients viz., protein, fat, carbohydrate etc. (Gopalan, Rama Sastri & Balasubramanian, 1989) in tables of food composition.

Food database should include as much specific and nutritionally relevant information as possible to represent the emerging interest of the consumer (Dennis, Ernstin & Hjortland, 1980).

Carbohydrates, an important ingredient in food, comprise a diverse group of plant substances, ranging from the sugars, starches, cellulose, and other non-starch polysaccharides. Importance of various food carbohydrates in normal and therapeutic diets has been widely recognized in recent years (Asp, 1994; Englyst & Kingman & Cummings, 1992; Jenkins et al., 1981).

In the last two decades earlier assumptions concerning the digestion of carbohydrate have been reviewed and shown to be invalid (Crapo, 1984; Englyst, 1992). The rate and extent of carbohydrate digestion is reported to be influenced by a variety of factors both intrinsic and extrinsic (Bjorck, Granfield, Liljeberg, Tovar & Asp, 1994; Colonna, Leloup & Buleon, 1992; Englyst et al., 1996). Therefore, the rate of starch digestion and absorption seems to be a determinant of the metabolic response to a meal (Englyst & Cummings, 1985). There are evidences that slowly digested and absorbed carbohydrates are favorable in the dietary management of metabolic disorders, such as diabetes and hyperlipidemia (Asp, 1994; Jenkins, Wolever & Kalmusky, 1985; Wursch, 1994).

The characteristic pattern of Indian diets is that of high carbohydrate-fiber (HCF) which is currently being

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advocated universally for the general population at risk of developing obesity, cardiovascular diseases and diabetes (Cummings, Englyst & Wiggins, 1986; Technical Committee, 1995; The Nutrition Sub-Committee, 1983; Thorburn, Brand & Truswell, 1987). Currently, average carbohydrate in Indian dietaries represents about 60-70% of calories of which 75% is starch derived mainly from cereals and pulses.

In-vitro studies on starch digestibility of foods as consumed by communities may provide useful information in initial screening of foods for predicting glycaemic responses. Though, glycaemic responses of Indian foods have been reported (Mani, Pradhan, Mehta, Thakur, Iyer & Mani, 1992; Raghuram, Pasricha, Upadhyaya & Krishnaswamy, 1987; Vishwanath et al., 1988), limited data on in-vitro starch hydrolysis in conventional Indian preparations is available (Asna & Shashikala, 1999; Roopa, Asna & Shasikala, 1998). Also, fractions of starch are reported to differ in their susceptibility to digestion (Englyst, 1992; Englyst, Kingman, Hudson & Cummings, 1996). No reports are available on the in-vitro measurements of nutritionally important starch fractions in conventional Indian foods.

Therefore, in the present investigation nutritionally important starch fractions as defined by Englyst et al. (1992) viz., rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) were measured in selected cereal-based preparations with suitable accompaniments. Rapidly available glucose (RAG) was also measured and a starch digestion index (SDI) was calculated. The proximate composition of the selected foods was also analyzed.

2. Materials and methods

2.1. Food preparation

All raw ingredients viz. cereals, pulses, spices etc., used in this work were purchased in bulk from the local market and were as fresh as possible. These ingredients were used in the preparation of the following foods: chapathi and Dhal; dosa and chutney; idli and chutney; pongal, poori and potato palya; ragi roti and chutney; rice roti and chutney; rice flakes upma; semolina idli and chutney and upma.

A description of the foods and the preparation methods involved is shown in Table 1. All the foods were ground to a paste in a mortar and pestle, dried in an oven at 50°C powdered and passed through a 60 mesh (British standard screen) for analysis of protein, fat, sugars, starch and dietary fiber. Each food was studied in three replicates.

Table 1
Food preparation data

Items	Major constituents
Cereal based preparations	
Chapathi	Whole wheat flour (60 g) kneaded into dough with 50 ml water, rolled into thin discs (diameter 12 cm), cooked on both sides on a griddle with oil (5 ml)
Dosa	Rice (raw 35 g, parboiled 15 g), black gram dhal (12 g), soaked (5–6 h), wet ground (paste), mixed, fermented overnight, ladleful of batter spread to form a thin pancake on a griddle, cooked on both sides with oil (5 ml)
Idli	Rice (raw 20 g, parboiled 40 g), black gram dhal (20 g) soaked (5–6 h), wet ground rice (coarse) and pulse (fine), mixed, fermented overnight and steam cooked in moulds
Pongal	Lightly roasted the pulse (split green gram 20 g), pressure cooked with rice (raw 50 g), water (150 ml) and seasoned with oil (5 ml), curry leaves, pepper and cumin seeds
Poori	Wheat flour (60 g) kneaded into dough (40 ml water) rolled into small discs (diameter 8 cm) and deep fried in oil
Ragi roti	Ragi flour (*Eleusine coracona)* (60 g), kneaded into dough (50 ml water) rolled into discs (diameter 12 cm), cooked both sides on a griddle with oil
Rice roti	Rice flour (50 g), kneaded into dough (90 ml warm water) rolled into discs (diameter 12 cm), cooked both sides on a griddle with oil (5 ml)
Rice flakes	Rice flakes (60 g), soaked (2–3 min), drained and seasoned with onion 20 g) and other ingredients (20 g) and other ingredients (mustard, green chilies, salt)
Semolina idli	Wheat semolina (55 g) roasted (1–2 min), mixed with curds (50 ml), water (120 ml) and salt, kept aside (30 min) and steam cooked in moulds
Upma	Wheat semolina (65 g) roasted (1-2 min), seasoned with onions (20 g) and other ingredients (mustard, green chili, salt) cooked in water (140 ml) till done
Accompaniments	
Coconut chutney	Coconut (fresh) 20 g, split skinned Bengal gram (10 g), green chilies and coriander leaves, salt were ground to paste
Dhal	Pulse (split green gram 16 g) cooked in water (150 ml), seasoned in oil (5 ml) with mustard, curry leaves and salt
Potato palya	Boiled and mashed potato (45 g), seasoned with mustard, curry leaves, salt, green chilies and onions (20 g)

2.1.1. Nutrient composition

All the foods were analyzed for protein (N×6.25), fat and free sugars using the AOAC method (AOAC, 1984). The starch content was determined by the method of Englyst et al. (1992).

2.1.2. Dietary fiber

Defatted residues of all the samples were finely powdered using a Warring blender, to pass through a sieve of 100 mesh. This fine powder of each of the samples was utilized for the estimation of soluble (SDF), insoluble (IDF) and Total dietary fiber (TDF) contents by the method of Asp, Johansson, Hallmer, and Siljesstrom (1983).

2.1.3. Measurements of starch fractions

The different starch fractions viz., RDS, SDS, RS and total starch (TS) were measured by the method of Englyst et al. 1992).

The various starch fractions were measured in 500 mg of food sample after incubation with invertase (EC 3.2.1.26: to hydrolyze sucrose), pancreatic alpha-amylase and amyloglucosidase (EC 3.2.1.3) at 37°C in capped tubes immersed in a shaker water bath. All foods were analyzed on an as-eaten basis and hence were freshly prepared before analysis. Since foods normally require chewing they were minced by a standard procedure. The incubation tubes contained glass balls for disrupting the food particles, guar gum was added to standardize the viscosity of the incubation mixture. A value for RAG was obtained as the glucose was released after 20 min (G_{20}). A second measurement (G_{120}) was obtained as glucose released after a further 100 min incubation. A third measurement (total glucose; TG) was obtained by gelatinization of the starch in boiling water and treatment with KOH (7 mol/l) at 0°C, followed by complete enzyme hydrolysis with amyloglucosidase. Resistant starch (RS) was measured as the starch that remained unhydrolyzed after 120 min incubation. Free glucose (FG) was also determined by treating the sample with acetate buffer and placing the tube in water bath at 100°C for 30 min. Simultaneous tests were run in a similar manner with the glucose standard. A blank tube containing buffer, glass balls and guar gum was also included to correct for the glucose present in amyloglucosidase solution. A summary of the analytical strategy used is shown in Fig 1.

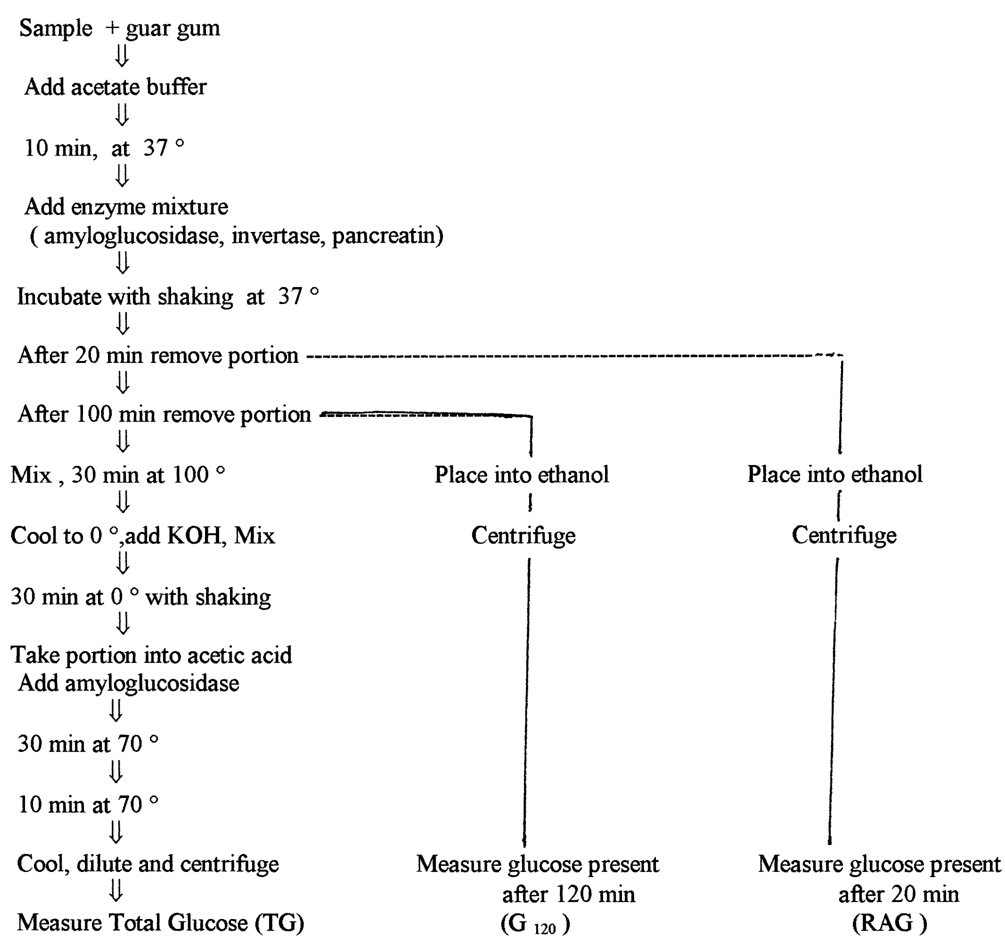

Fig. 1. A summary of the analytical strategy for measurement of rapidly available glucose, total glucose and glucose released by 120 min of incubation.

Glucose was estimated in all the samples using glucose oxidase/peroxidase diagnostic kit (Dr. Reddy's Laboratories, Hyderabad).

2.1.4. Treatment of data

The values for different starch fractions of TS, RDS, SDS and RS were obtained by combining the values of G20, G120, FG and TG.

$$TS = (TG - FG) \times 0.9$$

$$RDS = (G120 - FG) \times 0.9$$

$$SDS = (G120 - G20) \times 0.9$$

$$RS = TS - (RDS + SDS)$$

A measure of the relative rate of starch digestion was calculated by the following equation.

$$\text{Starch Digestion Index (SDI)} = \frac{\text{Rapidly didestible starch}}{\text{Total starch}} \times 100$$

2.2. Statistical analysis

The data on nutrient composition, different starch fractions and SDI are expressed as mean and standard error. Linear correlations between RAG and starch fractions viz., SDS, RDS and SDI, between SDI and starch fractions SDS, RDS and RS and between SDS and RDS were determined separately for foods with and without accompaniment.

3. Results

3.1. Nutrient composition of the selected foods

Nutrient composition of the cereal-based foods (with/without accompaniments) are shown in Table 2. On a dry basis, the macro nutrient composition varied depending on the ingredients used in the preparations. The protein content of five cereal preparations (without accompaniment) viz., chapathi, dosa, idli, poori and semolina idli were in the range of 11–13%,

The fat content of poori was the highest (24%) as it was a deep-fried product. The fat content of other foods ranged from 5–13%.

Addition of a suitable accompaniment to the cereal "entré" resulted in a moderate increase in both the protein and fat content of foods (Table 2).

All the foods contained low amounts of free sugars, ranging from 2.1–7.5% and 2–4.1% in foods with/without accompaniments, respectively. The total starch content in the foods on a dry basis ranged from 40 (poori) to 57% (chapathi) in foods without accompaniment. Addition of accompaniment decreased the TS content in six foods except in poori.

Table 2
Nutrient composition of the cereal-based food preparations[a]

Foods	Protein (g) N × 6.25	Fat (g)	Free sugars (g)	Starch (g)	Dietary fiber (g)	
					SDF	IDF
Chapathi	12.9±0.2	7.1±0.2	3.8±0.03	57.0±1.6	1.9±0.3	6.9±0.5
Dosa	12.6±0.3	13.6±0.3	2.1±0.1	46.1±2.4	1.4±0.2	5.3±0.7
Idli	12.5±0.2	2.7±0.2	2.0±0.1	54.2±0.7	1.4±0.3	9.9±0.6
Pongal	13.1±0.3	12.8±0.3	3.0±0.2	54.0±1.3	0.6±0.3	8.2±0.6
Poori	11.6±0.5	24.6±1.1	3.9±0.6	40.3±0.5	1.4±0.3	6.4±0.4
Ragi roti	8.7±0.1	12.5±0.2	3.9±0.3	45.6±2.3	0.9±0.2	13.4±0.5
Rice roti	8.2±0.3	11.2±0.3	2.7±0.6	50.2±2.0	0.7±0.1	4.8±0.2
Rice flakes upma	7.9±0.2	9.9±0.8	3.3±0.2	50.1±0.7	2.0±0.2	9.0±0.2
Semolina idli	11.3±0.2	5.6±0.2	2.0±0.1	54.9±2.9	2.1±0.3	2.5±0.1
Upma	10.8±0.3	12.3±0.7	2.7±0.2	48.2±0.9	2.8±0.1	6.2±0.2
With accompaniments						
Chapathi and dhal	13.7±0.1	8.2±0.6	3.5±0.1	45.1±0.9	3.3±0.4	10.9±0.7
Dosa and chutney	14.3±0.3	18.2±0.8	2.1±0.1	40.1±0.6	2.0±0.1	12.0±0.3
Idli and chutney	15.1±0.1	12.9±0.8	2.2±0.1	53.0±0.8	1.4±0.4	10.8±0.7
Poori and potato palya	15.2±0.2	26.4±0.4	7.4±0.5	57.0±0.7	3.0±0.6	15.0±0.4
Ragi roti and chutney	11.1±0.2	21.1±0.6	3.2±0.3	39.0±0.6	0.1±0.3	13.6±0.7
Rice roti and chutney	10.1±0.4	19.5±0.6	2.2±0.5	37.5±1.1	4.0±0.3	6.7±0.8
Semolina idli and chutney	13.3±0.3	16.4±0.2	2.1±0.1	51.3±0.9	2.5±0.9	8.6±0.3

[a] g/100g dry basis, values are mean of three replicate analyses. SDF, estimation of soluble, IDF, insouble.

The IDF and TDF content of chapathi and poori and ragi roti were higher than the values for other foods. The IDF and SDF values for all the foods increased on addition of an accompaniment, the exception being foods viz., idli and semolina idli. The TDF content of chapathi is dependent mainly on the extraction rate of wheat flour used. As the extraction rate increases the TDF increases, almost to the levels found in the whole grain (Prasad, Farhath Khanum, Siddalinagswamy & Santhanam, 1995)

3.2. Nutritionally important starch fractions

The total starch content and its fractions in foods (with/without accompaniment, on an as eaten basis) is shown in Table 3. The TS content of the foods, without accompaniment ranged from 20 g in poori to to 38 g in rice flakes upma. The highest levels of RDS were found in ragi and rice rotis followed (17 and 16 g, respectively) by pongal (11 g). In other foods, it ranged from 2.5–5.2g.

The highest level of SDS was found to be in chapathi (26 g). Foods like upma, dosa, idli, poori and semolina idli also contained substantial amounts of SDS (14–19 g). The lowest values (2.6–6.5 g) were found in both rotis, rice flakes upma and pongal.

The amount of SDS appeared to be inversely related to the amount of RDS and was therefore low for rotis and pongal and relatively high for other foods. Similar observations have been reported by Englyst et al. (1992).

The foods containing the most RS were rice flakes upma (28 g) semolina idli and rice roti (9–11g). The large amounts of RS in rice flakes upma may be indicative of incomplete gelatinization during preparation, moreover the flaking process may render the starch resistant to enzyme action. Significant amounts of RS in processed foods like pasta, corn flakes have been reported. The RS content in foods is reported to be dependent on the processing conditions and source of starch (Goni, Garcia, Manas & Saura-Calixto, 1996).

Addition of accompaniment to the foods had varied effect on TS and its fractions. In most foods the RS content was increased, particularly in chapathi and poori. In rotis, the addition of chutney as an accompaniment decreased the RDS and increased the SDS content. In other foods, i.e. dosa, idli and semolina idli, starch fractions did not vary on the addition of chutney.

Table 4 shows the ranking of foods by values for the RAG content (g/100 g) of foods as eaten and the SDI values. The ranking for many foods was not very different between the two systems. High amounts of RAG were found in rice and ragi roti. The addition of an accompaniment decreased RAG values in foods, i.e. in rotis, followed by chapathi. This is similar to reports which state that foods with low RDS have low RAG values (Englyst et al., 1992; Englyst & Hudson, 1996). The highest SDI values for foods without accompaniment were obtained for ragi roti (55), rice roti (51) and pongal (48). In comparison, the rate of digestion was considerably lower for the other seven foods, the SDI values ranging from 10–15.

The addition of an accompaniment decreased the SDI in three foods viz., poori, ragi and rice roti. Depending on the accompaniment, the digestibility of the 10 foods varied, with SDI values ranging from 14–26.

Table 3
Nutritionally important starch fractions in cereal-based preparations[a]

Foods	Dry matter %	Rapidly digestible starch (g)	Slowly digestible starch (g)	Resistant starch (g)	Total starch (g)
Chapathi	55	5.2±0.1	26.1±0.03	1.5±0.2	32.7±1.6
Dosa	30	3.2±0.2	15.1±0.1	8.1±0.4	26.4±2.3
Idli	36	3.0±0.2	16.7±1.0	9.7±0.1	28.7±1.3
Pongal	32	11.0±0.3	6.6±0.2	5.2±1.3	22.7±1.3
Poori	65	2.6±0.1	15.0±0.8	0.6±0.2	18.1±0.5
Ragi roti	50	17.5±0.2	2.7±0.3	11.2±0.5	31.0±2.0
Rice roti	38	16.2±0.3	3.7±0.6	11.6±0.9	31.5±2.1
Rice flakes upma	67	4.5±0.8	5.8±0.2	28.3±2.5	38.4±0.7
Semolina idli	33	3.1±0.4	16.2±0.5	9.9±0.4	28.9±2.9
Upma	31	4.8±0.7	19.2±0.3	2.8±0.9	26.0±0.9
With accompaniments					
Chapathi and dhal	44	11.0±0.6	10.2±0.4	20.1±0.9	41.1±0.4
Dosa and chutney	32	4.2±0.8	15.1±0.1	10.1±0.2	29.0±0.1
Idli and chutney	40	4.9±0.8	15.8±0.1	9.8±0.2	30.6±0.6
Poori and potato palya	44	4.4±0.4	11.1±0.5	5.6±0.2	21.9±0.6
Ragi roti and chutney	48	3.8±0.6	12.1±0.3	11.8±0.2	27.7±0.6
Rice roti and chutney	42	3.8±0.6	12.8±0.5	11.8±0.3	28.7±0.3
Semolina idli and chutney	36	4.4±0.2	16.1±0.1	9.8±0.1	30.3±0.3

[a] g/100 g fresh basis, values are mean of three replicates

Table 4
Ranking of foods by rapidly available glucose (RAG) and Starch Digestibility Index (SDI) values

FOODS	RAG (g/100 g)	SDI
Upma	6.6	14
Poori	6.7	12
Rice flakes upma	7.7	11
Idli	10.0	10
Semolina idli	10.1	10
Chapathi	10.3	15
Dosa	11.0	12
Pongal	16.0	48
Rice roti	25.1	51
Ragi roti	26.8	55
With accompaniment		
Poori and palya	10.2	20
Semolina idli and chutney	11.1	14
Dosa and chutney	11.5	14
Idli and chutney	11.8	16
Chapathi and dhal	15.8	26
Ragi roti and chutney	17.0	23
Rice roti and chutney	18.0	23

Table 5
Correlations between study parameters[a]

	Foods without accompaniment (8 d.f.)	Foods with accompaniment (5 d.f.)
SDI and		
1. RAG	0.92**	0.78*
2. SDS	−0.53^{NS}	−0.90**
3. RDS	0.97**	0.52^{NS}
4. RS	−0.13^{NS}	−0.43^{NS}
RAG and		
1. SDS	−0.68*	−0.49^{NS}
2. RDS	0.96**	0.19^{NS}
SDS and RDS	−0.72*	−0.51^{NS}

[a] d.f., Degree of freedom; NS, not significant
*$P<0.05$
**$P<0.01$

3.3. Relationship between starch fractions, SDI and RAG

Table 5 shows the correlation coefficients obtained by regression. All foods (with/without accompaniment) showed a significant positive correlation between SDI and RAG ($r=0.92$, $P<0.01$; $r=0.78$, $P<0.05$) and between SDI and RDS ($r=0.97$, $P<0.01$). SDI was inversely related with SDS (r −0.90, $P<0.01$) in foods with an accompaniment, indicating the influence of an accompaniment on the rate of starch digestion. Good correlation was found between RAG and the two important starch fractions (RDS and SDS) in foods without an accompaniment only. The inverse relation between amount of SDS and RDS was seen in foods both with and without an accompaniment, however it was significant (r = −0.72, $P<0.05$) only in foods without an accompaniment. Thus, addition of an accompaniment appeared to alter the nature of relationship between starch fractions.

4. Discussion

The present study used an in vitro procedure for measuring nutritionally important starch fractions in some selected cereal preparations (with/without accompaniments). Measurement of RDS, SDS and RS provide means for predicting the rate and extent of starch digestion in the human small intestine (Englyst & Hudson, 1996; Technical Committee, 1995). The in vitro RAG values were useful in predicting glycaemic response to dietary carbohydrates (Englyst, Veenstra & Hudson, 1996). It is of importance that the in vitro procedure should simulate starch enzymatic digestion at the best possible rate. In the procedure used (Englyst et al., 1992) in this work, foods are analyzed with minimal pre-treatment on an as-eaten basis.

In Indian preparations, differences in starch digestibility occur due to the raw ingredients used, pre-processing treatments, time and working procedures and the type of accompaniment it is usually eaten with. Foods like chapathi, dosa, idli, poori and rotis are generally eaten with accompaniments, while foods like upma, pongal are consumed without accompaniments. The results reveal that the course of starch hydrolysis is characteristic for each food. Foods like dosa, idli and poori with suitable accompaniments, showed low values for both RDS and RAG, which is similar to available reports (Asna & Shashikala, 1999; Roopa et al., 1998). The low RDS may be attributed to the slow and incomplete digestion of starch in these foods as starch granules may be encapsulated by cell walls.

Part of the starch being accounted as SDS in most foods is clearly the result of starch being trapped within cell-wall structures. The starch in chapathi and dhal, dosa and chutney, idli and chutney and semolina idli and chutney was digested in vitro much more slowly than that in ragi roti and rice roti. Hence, in these foods the SDS and RDS varied widely.

Addition of an accompaniment to the cereal based preparations altered the starch profile in most foods. This indicates that the amount of RDS and SDS in foods can be manipulated relatively simply, by varying the type of accompaniments. However, more data are needed regarding in vitro and in vivo experiments to substantiate this implication.

The type of cereal starch present in starch granules may also influence its digestibility (Englyst & Cummings, 1985; Englyst, Veenstra & Hudson, 1996). Starch in cooked potatoes is reported to be rapidly digestible as compared to raw potato (Englyst & Cummings, 1985).

In the present study, the addition of potato palya to poori increased the RDS, TG and SDI. A highly significant correlation was obtained between SDI and RAG in all foods both with and without accompaniments, whereas the significance between SDI and RDS was limited to foods without accompaniments and also the correlation between RAG and SDS was highly significant only in foods without accompaniments. The presence of an accompaniment nullified the effect, as RAG did not relate with RDS, SDS. Thus, the different combinations of a cereal entré with the accompaniment appear to determine the rate and extent of starch digestibility.

5. Conclusion

The results suggest that identification of specific health benefits related to ingestion of various types of starch will be possible only if separate measurements of starch fractions are available. Then, the expected rate and extent of digestion in the gut can be controlled by choice of ingredient, cooking method and type of accompaniment for the benefit of the target population. From the findings of the study, it appears that nutritionally important carbohydrates serve as markers for specific dietary recommendations.

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