REVIEW

Resistant starch in common starchy foods as an alternative to increase dietary fibre intake

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Summary
Nutritional classification of dietary saccharides considers as indigestible saccharides those that are incompletely or not absorbed in small intestine. Resistant starch (RS) as a part of dietary fibre (DF) is a type of indigestible saccharide. The addition of natural RS from some fruits, legumes or cereals to commonly eaten starchy foods is a good alternative to increase the DF intake representing, at the same time, new uses for uncommon sources of DF. This review deals with RS contents of commonly consumed starchy foods and shows their potential health-beneficial properties in situations where glucose tolerance is impaired, such as diabetes mellitus or obesity. For example, the current daily intake (193 g per day, fresh basis) of maize-tortilla in Mexico represents 1.8 g RS. However, tortilla prepared by blending maize with flaxseed (20%) exhibits a notably higher RS content (8.5 g per day). These staple foods added with natural RS sources show low or moderate in vitro starch hydrolysis rates and predicted glycaemic indices. Current nutritional and technological trends include the development of new formulas for traditionally consumed products. The combination of starchy foods with high RS content and/or the addition of natural RS sources to common food products could help to reach this objective.

Keywords
resistant starch; starchy foods; glycaemic index; dietary fibre; maize; banana; legumes

Dietary saccharides represent a range of chemical compounds. Biological origin and food processing have an important role in determining the overall attributes of the food matrix, which can have a major impact on the physiological handling of the ingested saccharides. The majority of dietary saccharides is represented by "available saccharides" also known as glycaemic saccharides, which includes those that are digested and absorbed in the small intestine and directly provide saccharide molecules for metabolism. In the available saccharides group, rapidly digestible saccharides and slowly digestible saccharides are included. The other group, now called "indigestible saccharides", comprises those that are incompletely digested or not digested at all in the small intestine or are poorly absorbed and/or metabolized. This definition is equivalent to the traditionally used unavailable and non-glycaemic terms [1].

Unfortunately, population in many countries has markedly high daily intakes of available saccharides due to the abuse of different types of products, such as soft drinks, sweet drinks, confectionary candies or sugar. This phenomenon is now known to be among the risk factors to develop chronic non-transmittable diseases including cer-

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tain kinds of cancer and the metabolic syndrome, which leads to cardiovascular pathologies and diabetes mellitus [2, 3].

Classification of indigestible saccharides includes resistant starch (RS), which is defined as the fraction of starch and the products of starch degradation that are not absorbed in the small intestine of healthy individuals [4]. For the same reason, dietary fibre (DF) is also considered as an indigestible saccharide. The latest definition of the Codex Committee on Nutrition and Foods for Special Dietary Uses (CCNFSDU) states that dietary fibre means saccharide polymers with ten or more monomeric units, which are not hydrolysed by the endogenous enzymes in the human small intestine and belong to the following categories; edible saccharide polymers naturally occurring in the food as consumed; saccharides that have been obtained from raw materials by physical, enzymatic or chemical means, and which have been shown to have a physiological effect of benefit to health, as demonstrated by generally accepted scientific evidence to competent authorities, and finally synthetic saccharide polymers which have been shown to have a physiological effect of benefit to health, as demonstrated by generally accepted scientific evidence to competent authorities [5]. In this regard, RS exhibits a number of physiological features such as reduced energy content, reduced or no effect on blood glucose levels, non-cariogenic effects, etc. [6], that allow for its inclusion as DF. This review addresses estimated RS contents associated to certain commonly consumed starchy foods and discuss the potential health-beneficial consequences of incorporating RS to some foods in situations where glucose tolerance is impaired.

Impact of food intake trends: the mexican population example

The latest Mexican Health and Nutrition Survey (MHNS-2006) [7], made by National Institute of Public Health, showed a prevalence of diabetes mellitus in 7% the adult population (20–40 years) and 20.1% for the elderly group (50–59 years). Obesity and overweight was estimated in 65% for adults (19–49 years), with an overweight prevalence of 71.4% for women and 66.7% for men [7]. These rates place Mexico among the countries with greater obesity and overweight indices in the world. Some of the principal factors contributing to this problem in the Mexican society are the poor quality of diets [8] and the low physical activity of the average inhabitant. In this regard, Mexico occupies the seventh world's place according to the Organization for Economic Co-operation and Development [9]. Recently the Mexican General Public Health Law was modified to include the development of nutritional education programs in elementary schools, in order to reduce the obesity prevalence [10].

The quality of diet is affected by changes in food consumption, high intake of available saccharides being one of the most important factors affecting this outcome. Starchy foods such as tortillas, beans and those added with RS-rich powders from different sources could be an alternative to increase the consumption of this particular form of DF.

Although official data regarding food availability in Mexico are not accurately updated (Mexican Nutrition Survey, MNS-1989; MNS-1999) [3, 11], it is widely accepted that sweet drinks, soft drinks and sugary foods (403 g per person and day) represent the most consumed foods. Other food groups importantly consumed by the population are: cereals (263.9 g per person and day), fruits and vegetables (203.8 g per person and day), and dairy products (137.6 ml per person and day). On the other hand, estimated intakes of fats and vegetable oils were 20 g per person and day [12].

Regarding DF intake, the average per capita total dietary fibre (TDF) value was 22.60 g per day in 1989 and, depending on the region of the country. the intake varied between 17.5 g per day and 27.1 g per day. The average consumption of soluble dietary fibre (SDF) and insoluble dietary fibre (IDF) were 2.89 g per day and 19.07 g per day, respectively. It is worth mentioning that the average consumption of DF in Mexico is relatively high compared to other North American or European countries. These data were obtained from a dietary survey and the dietary fibre composition of Mexican foods [13].

No more recent data about DF intake by Mexicans are available. Also, the Food and Agriculture Organization/World Health Organization considers that a healthy diet should provide around 25–30 g DF per person and day or 12 g DF/4186.8 J. Regarding fibre quality, at least a third should be SDF [14].

Cereals and legumes are rich in saccharides, where starch and DF are main components. The main fractions in cereal grains, accounting for up to 50–70% of the dry matter, are saccharides. Of these, starch and non-starch polysaccharides (DF) are major constituents.

Available data from last MNS-1989 [11] and MNS-1999 [3] indicated that cereal grains most frequently consumed by the Mexican population were maize (*Zea mays*;186.8 g per person and day, dry basis) and wheat (*Triticum annum*; 63.3 g per person and day, dry basis) [12]. Bread and pasta obtained from wheat, as well as tortilla and other related maize-based food products, are some of the main staple foods in both urban and rural areas in Mexico. Tortilla is obtained by an ancient Mexican process called "nixtamalization" where maize grains are cooked with alkali (i.e. lime). The alkaline-cooked maize grains, named "nixtamal", are ground to yield a soft dough known as "masa", which is used in the preparation of tortillas and other related maize-based foods. Recent information supplied by the GRUMA industrial group, leader in nixtamalized maize flour production for tortilla preparation, indicates that the actual daily consumption of maize tortilla in Mexico is 193 g per person and day (wet basis), which represents about 8 tortillas per day [15].

Consumption of dried legumes by Mexicans was reported to be 35.3 g per person and day (dry basis) [12], where common beans (*Phaseolus vulgaris*) are the most frequently consumed pulse. This has a considerably high saccharide content, ranging between 55% and 65% (dry matter). Starch and DF are also the major constituents, including significant amounts of indigestible oligosaccharides [16].

Starch digestibility

The digestibility of starch in foods may vary widely [17]. Hence, a nutritional classification of dietary starch has been proposed which takes into account both the kinetic component and the completeness of its digestibility. The classes are as follows [18]:

a. rapidly digestible starch, which occurs in recently cooked foodstuffs, with important levels of starch that is rapidly and completely digested in the small intestine;
b. slowly digestible starch, is generally found in whole or partly milled cereals, legumes, unripe fruits, which are digested slowly but completely in the small intestine, and finally
c. indigestible starch or resistant starch fractions.

The main classification of RS was proposed by Englyst et al. [18] based on the nature of the starch and its environment in food:

– RS1 corresponds to physically inaccessible starches entrapped in the cellular matrix,
– RS2 are native uncooked starch granules in foods such as raw potato or banana,
– RS3 are retrograded starch fractions formed after cooking and storage of foods at low or even room temperature, and
– RS4 encompasses indigestible fractions in chemically modified starches.

RS in foods affects a number of physiological functions and it has been suggested to have different effects on health, including reduction of the glycaemic and insulinemic response to food as well as hypocholesterolemic actions and protective effects against colorectal cancer [19, 20].

Resistant starch in starchy foods

There are numerous clinical and epidemiological studies supporting the contribution of soluble dietary fibre (SDF) to lowering the rates of diabetes, cardiovascular hearth diseases and cancer in human populations. Furthermore, beneficial effects of DF on the maintenance of gastrointestinal health have been attributed mainly to SDF [20].

The conventional DF assessment method [21] does not discriminate between non-starch polysaccharides and RS, which is normally included in the insoluble dietary fibre (IDF) fraction. Thus RS is part of the so-called indigestible fraction of foods [22].

Interest in RS has increased significantly during the last two decades, mostly due to its capacity to produce important levels of butyrate after fermentation in the colon, a feature that RS shares with SDF. Butyrate and other RS fermentation products may be important for colonic epithelial cell health through different mechanisms, such as effects on bile acids and modulation of nitrogen metabolism [19]. DF may be incorporated to common foods through the addition of RS-rich ingredients. A number of analytical methods have been proposed and provide different estimates for the RS contents in most isolated starch preparations and starchy foods [18, 23–25]. One of the most easily performed assays is that developed by Goñi et al. [25] in which, briefly, samples are milled (dry samples) or homogenized (wet samples), defatted when fat content is ≥ 5%, and incubated in sequence with pepsin and pancreatic α-amylase. The post-digestion water-insoluble RS-containing residue is then collected by centrifugation. This method does not involve the use of non-physiological digestive enzymes, such as fungal amyloglucosidase, and considering the procedure duration and costs, it compares favorably with other protocols including those of Berry [26], Englyst et al., [18], Champ et al. [19] and official method of AACC [27].

Addition of natural resistant starch sources to common starchy food

The addition of uncommon starch sources, such as plantain, fruits or certain seeds such as flaxseeds or amaranth, to different products and its influence on the nutritional value has been studied [28–30]. Positive functional changes such as increased RS contents, slowed-down starch digestion and lower predicted glycaemic index were reported.

Maize-based foods

As previously mentioned, maize tortilla is a staple food for the Mexican population, which makes it a dietary item with a potential to be improved by the addition of different ingredients conferring health-beneficial properties.

The approximate composition of tortillas with or without the addition of flaxseed and amaranth are shown in Tab. 1. Moisture in tortillas added with flaxseed is lower than in a control tortilla. This is due to the hydrophobic character imparted by the oil content in flaxseed. Moisture content in conventional tortillas might change depending on the conditions prevailing during "nixtamalization", ranging between 35% and 50% [31]. The maize variety used may also influence the final product moisture. For instance, blue maize tortillas exhibit lower moisture content (34.7%) than white tortillas (38%) prepared under identical conditions [32]. On the other hand, increased protein and fat contents were observed in maize tortilla added with flaxseed. However, these composite tortillas still show a much lower fat content than most industrially produced cereal-based foods. The increase in protein content in flaxseed-added tortilla might be important not only from the nutritional point of view but also for the interactions that may occur between protein and starch, leading to reduced starch retrogradation proclivity and softer texture [33, 34].

Maize tortilla obtained by maize "nixtamalization" process is considered as a source of DF, with contents around 10% [35]. Starch is the main component in this staple food, and its RS has been evaluated as a part of DF [28, 30, 32, 33, 36]. RS contents in different maize tortilla samples may vary depending on the cornmeal used. Tab. 1 shows how the addition of a different ingredient or the combination of tortilla with other food such as beans (a traditional culinary combination used in Mexico and Central America) leads to increased RS contents. Considering that a daily consumption of maize tortilla is 193 g per person (fresh basis, 40% moisture), a figure of about 1.8 g RS results. However, tortilla prepared by blending maize with flaxseed (20%) exhibits a higher RS content (8.5 g per·day). The intake of certain fibres, particularly soluble and viscous SDF, is usually associated with moderate postprandial glycaemic responses, a property of importance in some dietetic treatments [37].

Wheat-based foods

Wheat and rice are the most consumed cereals worldwide. Wheat is used in an extensive variety of foods, such as pasta (spaghetti, noodles, fusilli, etc.), breads, cookies and other foods. In general, pasta is considered a slowly digestible starchy food, a feature governed by the particular physical characteristics of the product [38]. Additionally, composite pasta may be easily prepared by blending semolina with other ingredients such as legumes (chickpea, beans), plantain starch, unripe banana flour and other uncommon ingredients.

Tab. 1. Chemical composition, available starch and resistant starch contents in different maize tortillas.

Sample (as eaten)	Moisture [%]	Fat [%]	Protein [%]	Ash [%]	AS [%]	RS [%]	Ref.
Commercial maize tortilla	n.d.	n.d.	n.d.	n.d.	65.0	2.14	[36]
Maize tortilla	47.6	4.27	9.1	1.31	68.5	1.92	[28]
Tortilla + 10% flaxseed	43.8	8.23	10.87	1.54	61.6	2.77	[28]
Tortilla + 15% flaxseed	44.1	9.98	11.60	1.44	58.1	3.25	[28]
Tortilla + 20% flaxseed	44.13	12.0	12.93	1.64	55.9	5.08	[28]
Maize/amaranth tortilla (80 : 20, dry matter)	5.46	4.81	10.60	1.52	73.3	1.4	[30]
Commercial maize tortilla-bean mixture (Taco)	n.d.	n.d.	n.d.	n.d.	52.58	3.93	[36]

AS – available starch, determined using the method of Holm et al. [63], RS – resistant starch, determined using the method of Goñi et al. [25], n.d. – not determined.

Tab. 2. Chemical composition, available starch and resistant starch contents in different wheat-based foods.

Sample (dry matter)	Moisture [%]	Lipid [%]	Protein [%]	Ash [%]	AS [%]	RS [%]	Ref.
Spaghetti							
Spaghetti (durum wheat flour)	n.d.	2.7	13.4	0.8	67.54	2.84	[39]
Spaghetti 80 : 20 (durum wheat flour/chickpea flour)	n.d.	3.3	15.9	1.4	63.28	3.48	[39]
Spaghetti 60 : 40 (durum wheat flour/chickpea flour)	n.d.	4.1	18.2	1.7	60.42	4.67	[39]
Spaghetti + 15% banana flour	8.50	0.51	10.86	1.49	n.d.	2.84	[40]
Spaghetti + 30% banana flour	6.25	0.48	9.35	1.58	n.d.	6.45	[40]
Spaghetti + 45% banana flour	4.95	0.46	8.07	1.83	n.d.	12.42	[40]
Noodles							
Wheat salted noodles	6.43	0.41	13.62	2.08	58.44	1.87	[41]
Wheat salted noodles/plantain starch 10%	5.68	0.34	12.01	2.28	68.38	2.07	[41]
Wheat salted noodles/plantain starch 20%	7.03	0.31	10.84	2.31	67.99	2.14	[41]
Wheat salted noodles/plantain starch 30%	7.60	0.33	10.18	3.12	70.90	2.16	[41]
Cookies							
Cookie with wheat germ	12.0	13.8	9.1	4.3	44.1	4.8g	[47]
Cookie with MDF (25 : 75)	11.9	13.0	8.3	4.3	41.1	4.4g	[47]
Control wheat cookie	4.49	12.6	11.9	0.37	37.2	1.48	[48]
Cookie added with RSRP (85 : 15, fresh base)	5.70	12.7	5.9	0.49	40.1	8.42	[48]
Bread							
Bread with wheat germ	31.5	16.2	11.4	3.2	60.9	6.3g	[47]
Bread with MDF (60 : 40)	26.0	11.2	10.2	3.9	41.1	7.3g	[47]
Control bread without banana flourh	13.7	18.4	4.1	2.0	59.1	1.0	[29]
Bread with banana flour *	26.6	14.2	9.8	3.3	54.9	6.7	[29]

AS – available starch, determined using the method of Holm et al. [63], RS – resistant starch, determined using the method of Goñi et al. [25], MDF – mango dietary fibre, RSRP – resistant starch-rich powder, n.d. – not determined.
* – values obtained by difference.

This addition brings about nutritional/functional properties like higher dietary fibre (non-starch polysaccharides and oligosaccharides).

The addition of legumes (e.g. chickpea) to spaghetti increased the protein content by 38% compared to control spaghetti, and the use of banana flour could decrease the fat content compared to the control sample [39–40]. On the other hand, these products had increased RS contents (Tab. 2). Among natural products, unripe banana shows the highest RS content ranging between 47.3% and 57.2%. RS values of the samples with added banana flour [40] were higher than those reported for composite noodles containing isolated plantain starch [41]. If it is considered that a regular serving contains 140 g ("as eaten") spaghetti, the RS in such a serving represent as much as 4 g, and the whole banana flour-containing spaghetti provide 17 g of RS. This value represents a noticeable increase in the intake of DF in terms of RS.

The instant noodle market is growing fast in the Western hemisphere [42]. Depending on the dehydration method used, instant noodles can be divided into fried and non-fried types [43]. Rendón-Villalobos et al. [41] elaborated non-fried noodles that were added with unripe plantain flour rich in RS. Lipid and protein contents in the plantain flour-containing noodles were lower than in the control product, possibly due to a simple dilution effect, since the plantain fruit has lower protein and lipid contents [44]. However, plantain starch-containing noodles did not show any significant increase in RS, a fact that stresses the importance of processing conditions for the starch digestibility properties of the final product.

Cookies and bread are well known widely consumed products. Nowadays, there is a need to find new sources of DF as ingredients for the food industry [45]. Fruit DF concentrates have better nutritional quality than those found in cereals, due to their superior balance between soluble and insoluble DF, and also because of their contribution in terms of DF-associated bioactive compounds (flavonoids, carotenoids, etc.) that provide antioxidant properties [46]. The approximate composition of cookies and bread enriched with either a resistant starch-rich powder (RSRP) from unripe banana, banana flour or with isolated mango dietary fibre (MDF) showed lower fat and protein contents than the corresponding reference product (Tab. 2). This reflects the diluting effect of the incorporated indigestible ingredient [29, 47, 48]. Interestingly, the fat content in these products was again significantly lower than in other industrially baked products.

Cookies enriched with a resistant starch-rich powder (RSRP) prepared from lintnerized banana starch [48] showed an elevated RS content (Tab. 2). RS as an uncommon type of DF is frequently present in unripe fruits such as bananas [29, 48, 49]. On the other hand, the content of DF in mango (MDF) was 281 $g \cdot kg^{-1}$ (dry basis) where a balanced SDF/IDF ratio has been reported, together with a relatively high starch content (29.9%) [47]. Considering the values recorded in fibre-rich cookies and bread elaborated with MDF instead of the more conventional wheat germ, the substitution did not result in increased RS content, contrary to the impact shown for the banana-containing pastry. Similarly, the addition of legume flours in bread making did not raise RS levels (Tab. 2).

Common bean varieties

Mexico possesses the wild type of five species of the *Phaseolus genus* of legumes, i.e., *P. vulgaris*, *P. acutifolius*, *P. lunatus*, *P. coccineus* and *P. polyanthus* [50]. Common beans (*Phaseolus vulgaris* L.) have an important place among legumes of major production and consumption in Africa, India and Mexico [51]. *P. lunatus* is a drought-tolerant species with average yields of 1500 $kg \cdot ha^{-1}$ and it is considered an efficient organic fertilizer [52].

Beans are a rich and inexpensive source of proteins (20–25%) and saccharides (50–60%) [53]. Starch and non-starch polysaccharides (dietary fibre) are predominant, with small amounts of oligosaccharides also present [16]. Total dietary fibre in dried *P. vulgaris* seeds has been reported between 4.5% and 22.6% for SDF and IDF, respectively [54]. The chemical composition of different *Phaseolus* varieties is shown in Tab. 3. Low fat and high protein contents are the main nutritional characteristics of legumes, which make this food group an interesting source of DF and vegetable protein. In addition to their particular composition, beans have been shown to have certain health-beneficial features, including a low glycaemic index [55].

The indigestible fraction of foods has been proposed as a more physiological definition of DF. It includes non-starch polysaccharides, lignin, resistant protein, RS and other associated compounds such as phytates, tannins and polyphenols. All of these components, together with RS and indigestible oligosaccharides, may be fermented to some extent in the large intestine by the colonic microbiota [22]. Raw and processed legumes contain significant amounts of RS in comparison with other products such as cereals, tubers and unripe fruits [16, 56, 57]. Depending on the botanic source, cooking process and storage conditions, RS in *Phaseolus* seeds can vary largely (Tab. 4).

During cooking, starch is gelatinized and rendered available, but a fraction of the gelatinized starch retrogrades upon cooling and, as previously mentioned, becomes resistant to enzymatic digestion [23, 57, 58]. Retrogradation is a process where starch chains form ordered structures in pastes, gels and cooked or baked foods during storage, whether in cold conditions or at room temperature, a phenomenon that is particularly marked in legumes [59]. The storage conditions and time generally increase the RS content in the seeds of different types of *Phaseolus* species as shown in Tab. 4 and Tab. 5. It is important to stress that beyond the starch content, the legume starch digestion rate is generally low and therefore the release of glucose into the bloodstream is slower after the ingestion of pulses [56].

Tab. 3. Chemical composition of different varieties of *Phaseolus*.

Sample (dry matter)	Moisture [%]	Lipid [%]	Protein [%]	Ash [%]	Ref.
Common bean (*Phaseolus vulgaris* L.) cv Mayocoba	9.65	1.98	23.41	4.5	[64]
Lima bean (*Phaseolus lunatus* L.) cv Comba violenta	9.7	1.3	24.0	4.3	[65]
Lima bean (*Phaseolus lunatus* L.) cv Comba floja	7.4	2.3	23.2	4.4	[65]
Lima bean (*Phaseolus lunatus* L.) cv Comba blanca	8.62	2.3	21.6	4.3	[65]

Tab. 4. Available starch and resistant starch contents in *Phaseolus* varieties.

Sample (dry matter)	AS [%]	RS [%]	Ref.
Black bean *Phaseolus vulgaris* L.			
Cotaxtla (cooked)	37.1	5.3	[36]
Black bean (boiled)	27.8	6.4*	[65]
Black bean (boiled, stored, reheated)	25.2	7.6*	[66]
Black bean (boiled, stored, microwaved)	24.8	7.0*	[66]
Common bean *Phaseolus vulgaris* L.			
Mayocoba (cooked)	22.8	6.4	[67]
Flor de Mayo (cooked)	32.2	2.4	[67]
Tacana (cooked)	32.2	5.1	[68]
Zitlala (cooked)	27.0	3.5	[68]
TLP19 (cooked)	28.4	4.9	[68]
Huasteco (cooked)	27.5	3.6	[68]
Veracruz (cooked)	21.7	4.0	[68]
Lima bean *Phaseolus lunatus* L.			
Comba violenta (cooked)	34.4	4.0	[65]
Comba floja (cooked)	33.4	3.8	[65]
Comba blanca (cooked)	32.9	4.5	[65]
Processed beans			
Canned bean	35.7	2.7	[68]
Commercial bean flour	38.3	6.1	[68]
Canned bean flour	32.3	5.7	[68]

AS – available starch, determined using the method of Holm et al. [63], RS – resistant starch, determined using the method of Goñi et al. [25], * – determined using the method of Saura-Calixto et al. [69].

Tab. 5. Available starch and resistant starch contents in cold-stored samples at 4 °C.

Sample (dry matter)	Storage time								Ref.
	0 h		24 h		48 h		72 h		
	AS [%]	RS [%]	AS [%]	RS [%]	AS [%]	RS [%]	AS [%]	RS [%]	
Commercial maize tortilla	65.2	2.14	64.4	2.6	60.6	2.7	59.7	3.8	[36]
Tortilla-bean mixture 60 : 40 (Taco)	52.5	3.93	51.8	3.9	49.6	4.2	48.3	4.3	[36]
Black common bean (*Phaseolus vulgaris* L.)	37.1	5.3	36.4	5.4	34.4	5.6	34.2	6.8	[36]
Bean (*Phaseolus vulgaris* L.) negro flour	29.6	6.4	30.6	6.6	33.1	6.7	31.2	6.5	[67]
Bean (*Phaseolus vulgaris* L.) negro whole	29.8	2.3	29.5	2.3	31.8	2.3	36.9	3.2	[67]
Bean (*Phaseolus vulgaris* L.) Flor de Mayo flour	29.8	5.2	30.4	5.4	31.6	5.7	27.2	5.7	[67]
Bean (*Phaseolus vulgaris* L.) Flor de Mayo whole	32.2	2.4	32.5	2.6	34.1	2.7	30.4	3.1	[67]
Cooked bean (*Phaseolus vulgaris* L.) Tacana	32.2	5.1	31.4	5.5	24.0	6.3	24.0	6.4	[68]
Cooked bean (*Phaseolus vulgaris* L.) Zitlala	27.0	3.5	23.2	3.4	19.0	4.0	14.5	5.6	[68]
Cooked bean (*Phaseolus vulgaris* L.) TLP19	28.4	4.9	28.3	6.0	28.2	6.3	24.2	6.4	[68]
Cooked bean (*Phaseolus vulgaris* L.) Huasteco	27.5	3.6	24.2	3.8	21.4	4.8	21.9	5.1	[68]
Cooked bean (*Phaseolus vulgaris* L.) Veracruz	21.7	4.0	20.0	4.7	13.8	4.2	14.2	5.0	[68]

AS – available starch, determined using the method of Holm et al. [63], RS – resistant starch, determined using the method of Goñi et al. [25].

Starch hydrolysis index and predicted glycaemic index of some starchy foods

The concept of a glycaemic index was developed to provide a numeric classification of saccharide-containing foods on the assumption that such data would be useful in situations in which glucose tolerance is impaired [37]. In a way, the glycaemic index concept was an extension of the dietary fibre hypothesis of TROWELL [60], who suggested that foods that are slower absorbed might have metabolic benefits in relation to diabetes and to the reduction of coronary heart disease (CHD) risk.

The contents of RS, the type of available starch and some structural features in starchy foods have influence on the starch digestion rate and therefore on the kinetics of glucose release into the bloodstream. The hydrolysis index (*HI*) is calculated as the area under the curve (0–180 min) of the in vitro enzymatic hydrolysis of a fixed amount of available starch in a chewed test product. It is expressed as a percentage of the corresponding area for a white bread reference sample, chewed by the same person. The average *HI* is calculated from the six digestion replicates run for each sample. The predicted glycaemic index (*pGI*) is obtained using the empiric formula (1) proposed by GRANFELDT [38]:

$$pGI = 0.862HI + 8.198 \quad (1)$$

for which the correlation coefficient (r) was 0.026 ($P < 0.00001$).

Tab. 6 shows different *HI* and *pGI* for different starchy products containing unconventional starch sources compared to the corresponding regular product. Different cultivars of *Phaseolus lunatus* show slightly different values. Starch in whole cooked legumes is retained within rigid cell walls of cotyledon cells. This, together with a high DF content (140–240 g·kg^{-1}, dry basis), results in

Tab. 6. Hydrolysis index and predicted glycaemic index in different starchy foods.

Sample	*HI* [%]	*pGI* [%]	Ref.
Control spaghetti (durum wheat flour)	84.08	80.68	[39]
Spaghetti 80 : 20 (durum wheat flour/chickpea flour)	72.50	70.70	[39]
Spaghetti 60 : 40 (durum wheat flour/chickpea flour)	61.78	61.45	[39]
White salted noodles	60.9	60.7	[70]
White salted noodles/plantain starch 10%	74.5	72.4	[70]
White salted noodles/plantain starch 20%	73.9	71.9	[70]
White salted noodles/plantain starch 30%	71.3	69.6	[70]
Control cookie	80.54	77.62	[48]
Wheat germ control cookie (75 : 25)	81.90	78.80	[47]
RSRP cookie (75 : 25)	60.71	60.53	[48]
MDF cookie (75 : 25)	54.98	55.59	[47]
Control bread	66.26	65.31	[71]
Wheat germ control bread (75 : 25)	71.22	69.59	[47]
Bread with banana flour	65.10	64.30	[29]
MDF bread (75 : 25)	54.98	55.59	[47]
Bread with chickpea flour (80 : 20)	44.92	46.92	[71]
Bread with chickpea flour (60 : 40)	30.71	34.67	[71]
Black bean (*Phaseolus vulgaris* L.) *var* Cotaxtla	21.3	27.0	[36]
Lima bean (*Phaseolus lunatus* L.) Comba violenta	35.8	39.1	[64]
Lima bean (*Phaseolus lunatus* L.) Comba floja	32.1	35.8	[65]
Lima bean (*Phaseolus lunatus* L.) Comba blanca	30.2	34.2	[65]
Canned faba beans	39.6	78.5	[72]
Commercial maize tortilla	77.57	75.0	[36]
Commercial maize tortilla-bean mixture 60 : 40 (Taco)	49.08	51.0	[36]

HI – hydrolysis index was calculated against white bread [38], *pGI* – predicted glycaemic index = 0.862 *HI* + 8.198 [38], RSRP – resistant starch-rich powder, MDF – mango dietary fibre.

a rather low rate of starch digestion. In addition to the intrinsic properties of legume starches, their cognate viscous dietary fibres have been suggested to slow down the diffusion of amylolytic products to the absorptive mucosa [37, 56], a possibility that might therefore decrease the diffusion rate of composite pasta starch digests.

From a nutritional point of view, legumes could bring about a lower hydrolysis index when added to common products. For instance, the properties of composite wheat/chickpea flour have been investigated. The *HI* and *pGI* obtained (Tab. 6) confirmed that the product retained the beneficial "slow digestion" features of starch in pulses [56, 61]. However, plantain-added noodles did not show reduction in *HI* and *pGI* (Tab. 6). Again, this observation makes evident the susceptibility of a particular starch ingredient to process-mediated alteration. The addition of DF or RS sources, such as RSRP or MDF, in wheat-based products promoted a decrease in *HI* and *pGI*. The slow hydrolysis of starch in RSRP-cookie and MDF-cookie is noteworthy and indicates that these ingredients affect the susceptibility to digestion of the available starch portions. The *pGI* suggests important "slow digestion" features for the samples added with banana and chickpea flour, and also with RSRP or MDF, which is in line with perceived health-beneficial characteristics of RS [19]. The *pGI* value determined in these samples suggests that the products have a low in vivo *GI*. In addition to the intrinsic properties of starch, the possible influence of the product compactness on the observed *HI* and *pGI* values cannot be ruled out. Commercial tortilla had a higher *HI* and *pGI* value than other wheat products. However, the combination of maize tortilla with common beans (60 : 40) results in a lower pGI, where the viscosity developed during digestion may be high enough to retard the absorptive phase of digesta, resulting in a rather "slow" feature [36, 61]. The pattern observed in samples added with RS or DF sources are important in the mechanisms governing postprandial glycaemia for wheat flour-based products [62] and foods with high RS contents, and combination of both, such as the traditional Mexican taco.

CONCLUSIONS

Low physical activity and poor diet quality are some of the numerous factors influencing the increased obesity, diabetes mellitus and cardiovascular diseases prevalence in many countries, such as Mexico. The addition of natural sources of RS to common starchy foods represents an interesting way to increase the intake of DF. Consumption of available saccharides in combination with slowly digestible or indigestible saccharides has a potential to retard the hydrolysis and predicted glycaemic index in different staple foods, which may be a useful dietary alternative in view of the currently elevated ingestion of available saccharides. Introducing specific changes in the composition of a traditional diet may bring about potential health benefits as those related with the increased intake of RS.

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Received 6 October 2010; revised 29 October 2010; accepted 6 November 2010.