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Mini Review

Low digestible starch and food industry: A changing paradigm

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Globally, starch based foods including staples are consumed most as they contribute maximum towards the daily per capita energy. While the carbaholic nature resulting high post prandial glycemic response has led to a starch dilemma and innovative low glycemic profile grains as well as products are thus the need of the hour. The presence of two nutritional fractions – slowly digestible starch (SDS) and resistant starch (RS) which endorse the low glycemic potency is thus supplemented in food industry for developing low glycemic food prototypes. The unique characteristic of RS like bland flavour, white colour, low water holding capacity along with its prebiotic potential has made them a valuable component in functional foods. Many strategies are currently applied to increase the proportion of SDS and RS including physical, chemical, enzymatic as well as their combinations. Thus, considering the changing paradigm, the aim of this review is to understand the basic concepts of starch digestibility, inherent factors affecting digestibility, applications in food industry, current strategies, commercial counterparts as well as existing dietary regulations.

Keywords: Dietary regulation, Glycemic response, Starch dilemma

Role of starch in nutrition is undeniable as the food pyramid recommends 6-11 serving of starch based foods per day, which accounts for 60-70% of the daily per capita energy. Being the major glycemic carbohydrate, during digestion it depolymerizes through the action of α-amylase and brush bordered amyloglucosidase enzymes into monomeric glucose form in the small intestine[1]. Staple cereals like white rice and its products have thus been known to generate high kinetic rate and glycemic response which relatively increase the insulin secretion[2]. Positive dependence exists between high glycemic index (GI), glycemic load (GL) and glycemic response (GR) after taking such carbaholic diets and thus known to be a major risk for chronic diseases like type 2 diabetes (T2DM)[3, 4.] There are mounting evidences also to share insights that Asians are more prone towards postprandial blood glucose spike with insensitive insulin response than Caucasians even for similar foods ingested, which escalated the risk chance for developing T2DM[5]. Diabetic challenge which we face in our country with regard to controlling carbohydrate consumption is that, rice/rice products are part of our culture and not just food for living. Thus reports even suggest that Indians could compromise health over food[6]. Thus an effective strategy for managing diabetes in India as well as in Asia would be to improve the carbohydrate quality through modifying the inherent GR of rice along with reducing the carbohydrate quantity. Meta-analysis in this direction, substituting conventional high GI foods with low GI foods endorsed clinical leg-up on glycemic control[7]. Thus to tackle the global economic burden due to chronic hyperglycemia, tailoring the inherent GR of starch rich staple cereals like rice and their products is the need of the hour. Much more, extensive research probing various factors affecting glycemic potential will assist in designing new food prototypes of low glycemic amplitude. Thus this comprehensive report briefly reviews on the basic concept of starch digestibility, inherent factors affecting starch digestibility, industrial applications, existing technologies to manufacture, commercial counterparts as well as existing dietary regulations.

Starch digestibility and nutritional fractions

Inherent GR depends on its complex starch hierarchy, which in turn affects the extent of starch digestibility as well as its absorption in the small intestine. Starch digestibility of food like rice is usually defined as GI and white rice is known to be high GI in nature[8]. Digestibility profile divides starch majorly into three types – Rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS). RDS is interpreted as the portion of dietary starch digested within 20 min (G_{20}), while SDS contributes to the extended GR *i.e.*, glucose released in about 240 min (G_{240}). RDS result in huge

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blood glucose fluctuation resulting oxidative stress resulting with disturbed glucose homeostasis. SDS is the most elusive fraction among three due to its transient nature and has not been clinically to such a significant degree to as RS. RS is the third portion, represented as the fraction of dietary starch which skips the enzymatic digestion in upper gastrointestinal tract. RS has also examined and known as beneficial as it evades human digestion and hence food rich in this fraction endorse its low digestibility nature[9]. Over and above, RS shares similar physiology with dietary fibre and act as carbon source for the colon gut microbiome releasing beneficial short chain fatty acids (SCFAs)[10]. SDS also report to have physiological consequences just as profound as RS but not detailed much due to the existing gap in research (Fig. 1).

Most recent publications[11, 12] classified RS into five sub categories: (i) RS1: resistance due to physical entrapment. (ii) RS2: resistance due to inherent high molecular ordered configuration. (iii) RS3: resistance due to change in molecular structure after cooking-cooling process (iv) RS4: processing induced modifications like newer chemical bonds and linkages. (v) RS5: resistance due to formation of amylose-lipid complexes inherently or due to processing. As RDS being positively correlated to GI, rice varieties rich in SDS and RS could solve the

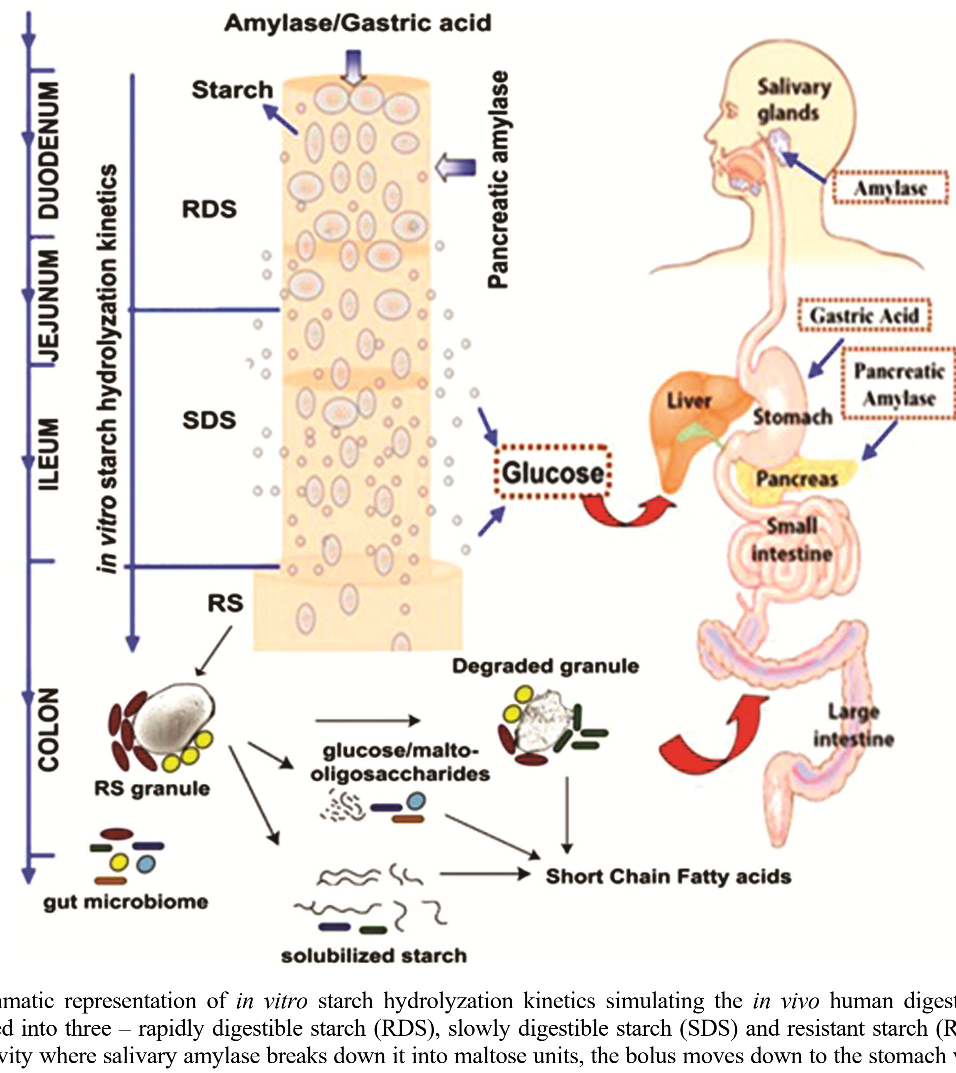

Fig. 1 — Diagrammatic representation of *in vitro* starch hydrolyzation kinetics simulating the *in vivo* human digestive system. [Starch fractions are divided into three – rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS). Starch digestion starts in the oral cavity where salivary amylase breaks down it into maltose units, the bolus moves down to the stomach where the enzyme is inactivated (due to the acidic environment). There is no carbohydrate breakdown in the stomach and the bolus moves to the small intestine. RDS fraction completely digests in the jejunum of small intestine, while SDS further continues till ileum. The pancreatic amylase breaks down the RDS and SDS fractions in the small intestine. RS after escaping digestion from mouth, stomach and intestine, moves to the large intestine (colon) where the RS granules are solubilized or fermented or bio-transformed into short chain fatty acids (SCFA) by the gut microbiome SCFAs. (Partially adopted from (https://www.cell.com/trends/microbiology/fulltext/S0966-842X(19)30239-2?rss=yes)]

aftermath of chronic hyperglycemia. Even though an inverse relation was expected between GI and RS, previous report by a researcher group[8] mentioned it's decisive. RS estimated till date in white rice varieties varied from 0.35% to 3.2%[8, 13]. As inherent RS content limited to less than 4% reported till date, high through put screening tools as well as efficient strategies have to be deduced in future to improve the RS content in rice. Many more RS profiling of rice varieties especially in the heirloom indigenous rice may share novel insights. Recently the role of SDS and RS together known as nutraceutical starch (NS) having reported to have role in anti-hyper glycemia, also underlines the fact that higher proportion of low digestible starch will be beneficial[14]. Fine tuning the inherent starch digestibility further by processing is possible only through a sound understanding on various inherent factors affecting starch digestibility.

Inherent factors affecting starch digestibility

Till date, numerous factors have been known to influence the starch digestibility like grain type, botanical origin, microstructure/molecular structure, starch composition (total starch, amylose, amylopectin), starch fractions (RDS, SDS, RS), other matrix components (protein, lipids and phenolics), physicochemical properties, cooking attributes, rheological and textural attributes[15] (Fig. 2)

Among the inherent factors, microstructure of the grain is vital in modulating the digestibility as they either prevent enzyme diffusion towards starch granule (*i.e.*, multi-layered pericarp) or enzyme adsorption to the granule, or ultimately the hydrolytic event[1]. The size, shape, surface pores, channels as well as cellular layers have known as major microstructural variations contributing difference in its digestibility. Other than the intactness of the natural grain matrix and the alterations in the microstructure (due to origin), certain processing conditions like milling or cooking has known to contribute towards higher gelatinization rate induced starch digestibility. A possible correlation between the microstructure and starch digestibility was recently reported by group of researchers[16] where, incomplete breakages in the bran layer and presence of fissures or cracks on the surface or incomplete disruption to germ was endorsed with increased gelatinization rate and associated GR. Other than that, cooking conditions also alter the texture of rice which in turn affects their digestibility induced GR. Texture is a multifactorial sensory property commonly studied as a gold standard for eating and cooking quality, while it also acts as a physicochemical trait correlating digestibility. The stickiness or hardness, majorly due to the differences in composition (amylose or amylopectin) ultimately affects the molecular structure of starch packing as well as crystallinity[17].

The amorphous or tight package at nanoscale influences amylolytic digestibility which in turn is dependent on the degree of polymerization (DP) of linear glucan (amylose) as well as branched glucan (amylopectin). It has been reported that easily digestible starch types are sticky and low in amylose content; while higher amylose variants found to be harder and less digestive[18]. Studies reported to have lower GT, enthalpy value and molecular crystallinity have lowered resistance towards enzyme digestion[19]. In comparison to low amylose and waxy phenotype, intermediate amylose starch showed much more stable molecular order due to higher proportion of stable double helices with stronger crystallites. Such hints correlated a possible relation between amylose and RS[19], while in contrary recent reported by a research group[13] justifies the role of other components

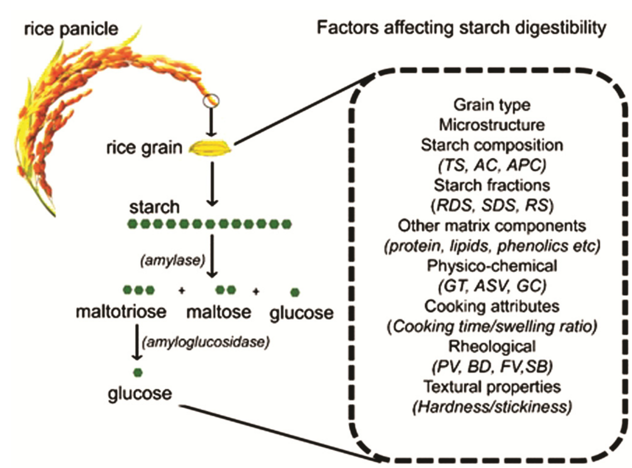

Fig. 2 — Mechanism of *in vivo* starch hydrolysis and various factors affecting it. [Rice contains about 78-89% starch and its hydrolysis occurs in two steps in human body. The illustration (left side) represents the action of carbolytic enzymes like amylase and amyloglucosidase. Step 1 in the digestion of starch is catalysed by salivary and pancreatic amylases which produce maltotriose, maltose and glucose. Step 2 of hydrolysis to glucose is carried out by brush bordered disaccharidases or glucosidases. Inherent factors which often interplay and affects the starch digestibility is presented on the right side of the illustration. TS- Total Starch; AC- Amylose content; APC –Amylopectin content; RDS – Rapidly Digestible Starch; SDS– Slowly Digestible Starch; RS- Resistant Starch; GT- Gelatinization temperature; ASV- Alkali Spreading Value; GC- Gel consistency; PV- Peak viscosity; BD- Breakdown viscosity; FV- Final viscosity; SB- Setback viscosity]

like amylopectin debranching rate as an indicator towards RS formation. Rice cultivars with similar amylose contents displayed different stickiness, which suggested that the proportion of amylose-amylopectin in the leached contents during cooking could be an indicator for texture[20]. Hence, the microstructure as well as texture depends on the molecular composition and configuration of amylose and amylopectin.

Among the components of starch having key role in digestibility, amylose has been well characterized since 1980s[21]. Starch gelatinization occurs during cooking is the initial step towards digestibility. During the process, starch granules absorb water and swells losing its molecular order. Over and above if continued it will melt the crystallites leading to leaching of linear amylose. Such leaching into the solution phase forms a protective layer around the granule prevents further swelling. This in turn reduces the accessibility of enzyme to penetrate further into the granule and reduce the digestibility by reducing the susceptibility of starch to digestive enzymes, as the swelling of starch granules increases the accessibility of enzymes to penetrate into the granules and thereby greater amylose content allows greater resistance to swelling and minimizes hydrolysis. Considering the impeccable role of amylose in starch quality, various molecular biology efforts have been taken to characterize the gene responsible for its synthesis — Granule Bound Starch Synthase (GBSS). The relationship between GBSS alleles and amylose content in different rice varieties was initially characterized by Dobo *et al.*[22], where different combinations of SNPs in exons 1(G/T), 6(A/C), and 10(G/T) was found to vary the amylose content. Low amylose varieties had TAC and TCC allele, intermediate amylose had GCC allele and high amylose varieties had GAC and GAT allele. The C/A polymorphism in exon 6 caused serine/tyrosine substitution which destabilize GBSS and result with low amylose phenotype. A positive correlation between RS content and *gbssI* expression in rice cultivars was reported by[8] and mutation within the GBSS has reported to increase the RS content[23]. They discovered that wild type GBSSI and SNP in *ssIIa* and *ssIIIa* zoomed the RS level to about 8.68%.

As the molecular configuration of starch is dependent on both components (amylose and amylopectin), the role of amylopectin towards digestibility has recently unraveled through advance studies involving size exclusion chromatography, crystallinity and electron microscopy. Li *et al.*[24] have reported that the molecular fine structure of amylopectin including size and chain-length distribution contribute to starch texture and digestibility. Syahariza *et al.*[25] highlighted that besides the composition, the intricate structural features of amylopectin may play compelling role in determining the hydrolytic rate of starch in cooked rice grains. Increased percentages of A-type crystalline structure and amylopectin side chains of DP 6-24 both have been shown to increase the rate of digestion[26], while B or V type contributed through compact crystalline packaging has shown to inhibit inside out digestion of starch granules. Manipulating amylopectin levels as well as its structure through engineering, various branching and debranching enzymes were carried out. Zhang and others[27] reported that slow digestion properties of cereal starches are associated with high levels of short amylopectin chains. Recent report by a research group[13] proposed the role of debranching enzyme, pullulanase towards accumulation of RS fraction in rice. Targeted mutagenesis in starch branching enzyme (SBE)*I* and *IIb* in rice through CRISPR/Cas9 has reported to increase RS to 9.8%, also demonstrated the role of amylopectin structure in starch configuration and digestibility[28]. Besides the significant role of composition, starch digestibility also depends on the physico-chemical attributes which in turn is depended on the structural hierarchy of starch at various scales.

Gelatinization attributes based on composition also well correlated with digestibility. Structural disruption due to gelatinization escalates its susceptibility to enzymatic hydrolysis *in vitro*, and thus increases its availability for digestion and absorption. Thus degree of gelatinization correlates positively to starch digestibility, in contrary gel consistency (GC) correlates negatively[29]. Hardness of GC has reported with higher amylose content and also known as an indication of longer cooking time. Cooking time being the process of gelatinization, has majorly related with amylose content as amylose acts as a diluent as well as inhibitor to swelling of starch, which causes the rice cultivars to have a longer cooking duration. Generally, varieties with shorter cooking time are digested faster as they are gelatinized more easily. Optimum cooking time is positively correlated with thickness of the grain which is difficult to digest than slender or thin grains. Alkali spreading value (ASV), which gives an estimate of the gelatinization temperature (GT) can also be used get a preliminary idea on eating quality[30]. ASV is negatively correlated with the amylose content and GT. A higher GT is known to have slower *in vitro* starch digestibility[31]. Rice varieties with lower values of ASV and GC will take longer time to cook and gets digested slowly since it has higher GT[32].

Rapid visco-analysis (RVA) based starch pasting profiles are determined as they may have potential to assess the quality of starch. Estimation of eating and cooking quality of rice starch using RVA revealed that setback (SB) and breakdown (BD) values play significant role as compared to peak viscosity (PV)[33]. Amylose content, a major determinant of pasting parameters, has been found to be negatively correlated to peak viscosity (PV) and breakdown viscosity (BV)[34]. A lower peak viscosity implies lower digestibility of gelatinized starch[34]. It has also been shown that higher setback values are linked to higher amylose in cooked rice[35]. Lower RVA parameters show a lower amount of liberated glucose, indicating their slower rate of digestion, promoting less GI. Such parameters can be used to screen rice varieties with lower digestibility and well suited for hyperglycemic patients.

Rice being the staple food for Asians, especially Indians, completely replacing the diet with other types of low digestible cereals like quinoa or millets is not a viable option. Even though there is a starch dilemma that all rice is hyperglycemic, India is blessed with a rich diversity of rice varieties but till date starch quality studies are lacking. Many inter-relationship studies have been conducted on understanding the dependency among starch quality parameters. Even though significant association is found, consistency was the major bottleneck due to the wide diversity of rice germplasm and the complexity associated with the inheritance in the quality parameters[36]. The most well associated parameters like amylose, RVA profiles and GC has also found to vary between '*indica*' and '*japonica*' subspecies[37,38]. Though some attempts were made to correlate various compositional and rheological parameters with rice starch quality using a predictive near-infrared spectroscopy (NIR) by Bao *et al.*[39] many factors like proportion of RDS, SDS, RS remained unaddressed in coherence with physicochemical and rheological parameters. A comprehensive study involving various deciding factors contributing towards digestibility is not yet known (Fig. 2). The explicit hidden mechanism of resistance of starch granules to hydrolysis is perplexing because all these factors are often interlinked. Hence, the established relationships among these parameters are not dependable or rational. It is necessary to test each parameter of rice starch quality that is considered important as per the objective of the genetic modification program. Being the assessment of rice starch quality parameters is a resource-intensive part in breeding, a predictive tool comprising all the possible variables affecting starch digestibility is the need of the hour.

Industrial applications and existing technologies to manufacture low digestible starch

Low digestible starch (LDS) including SDS and RS have immense role in overall quality of food by lowering the glycemic potency, improving the texture quality as well as eating/cooking qualities. Compared to SDS, RS has been much more studied due to the advancement in extraction and quantification of different types. Many more the physiological similarity with dietary fibre also embraced RS as a potential prebiotic with multitude of functional properties like increasing crispiness, low oil binding in fried foods, high water binding capacity, good extrusion quality, etc.[11]. High amylose starch being low digestible, have low water holding capacity and higher water binding capacity and thereby decreased water activity and increased product shelf life. Also, supplementation of such low digestible starch in dairy products, thus prevents ice crystal formation, vital for the creamy texture for ice cream. Among the RS types, RS 3 is found to be thermally more stable during frying or high temperature drying, hence play immense role in baking industries[11].

A wide range of potential health benefits has been associated with SDS and RS fractions based on diet supplementation studies[40]. Based on the factors discussed above, mainly two approaches have been followed to improve their content, either through altering the molecular structure or increasing the complexity of the matrix. For altering the molecular structure, various thermal processing strategies, pre-treatments and combination conditions has been carried out till date which led to increase in starch digestibility (Table 1). Extrusion cooking followed by retrogradation has been successfully practiced to reduce digestibility through increasing RS3

Table 1 — Processing strategies to improve the low digestibility of starch

Processing strategies to prepare/improve low digestible starch	Fraction enhanced
Extrusion cooking	RS3[41]
Extrusion cooking + refrigeration	RS3[42]
Partial acid hydrolysis	RS2[43]
Enzymatic debranching	RS3[44]
Retrogradation	RS3[45,46]
Parboiling	RS[47]
Heat Moisture treatment (HMT)	RS3[48,49]
Parboiling + HMT	SDS, RS[50]
Annealing (ANN)	RS3[50]
ANN + HMT	SDS, RS3[51,52]
Chemical Modifications	RS4[53,54]
HMT + Chemical modifications	RS3+RS4[55]
Dual autoclaving-retrogradation	RS3[56]
Single modification treated (SMT) starch	RS3/RS4[54]
Dual modification treatment (DMT)	RS3+RS4[54]
Enzymatic modification with 4-α glucanotransferase	RS[57,58]

proportion. Even though it's known that retrogradation occurs after formation of new intermolecular hydrogen bonding which endorse better stability and less digestibility, few studies reported conflicting data[11,59,60]. A combination of extrusion cooking and low-temperature storage was also carried out by Neder-Suárez *et al.*[42] where they reported an increase in total RS. Acid hydrolysis being a major chemical modification altering the starch granule morphology as well as digestibility, partial acid-hydrolysis has reported in reducing digestibility through increasing RS2 fraction[43]. Debranching enzyme pullulanase has been recently shown to have role in RS formation in rice[13]. However, debranching treatment of starch have been known to lower the digestibility. RS content increases sharply with amount of the debranching enzyme (12 U/g) as well as with time (for 32 h) of incubation under optimum conditions[44]. Reed *et al.*[45] attribute the increased levels of RS observed in fried-rice samples to the retrogradation during the cold storage and to a lesser extent to "amylose-lipid complex" formation. Partially-gelatinized rice starches, with higher amount of crystalline ordering, showed more resistance to enzymatic digestion as compared to retrograded samples[46]. Parboiling is an another process where rice gets partly boiled in the husk, with three steps: soaking, steaming and drying, were also found to lower the starch digestibility. An interesting observation was seen after parboiling when native and typical A-type crystalline structure in starch transformed into a combination of A, B and V types. V type starches are known for their resistant to hydrolysis. Gunaratne et al. found that the parboiling process reduced swelling volume and amylose leaching, which resulted in retaining of amylose[47]. Cheng *et al.*[61] reported that parboiling also reduced the estimated GI which was explained in such a way that parboiling caused breakage in the protein structure which acted as a barrier between starch and hydrolytic enzymes.

Among the processing strategies, thermal processing methods are most widely adopted and among which microwave irradiation has been well embraced by the food industry. Studies observed an irradiation followed by cooling resulted with increased RS3 fraction contributing towards low starch digestibility[62]. RS 1, 2 and 5 being inherently found in the source, while RS3 and RS4 content have been modulated through processing strategies. Several combinations of time-temperature treatments have been studied in this direction focusing RS3 and chemical processing like esterification, cross-bonding, substitution in case of RS4[63]. Among different processing strategies, heat moisture treatment (HMT) and annealing (ANN) are the hydro-thermal processes directed to change starch properties by manipulating the temperature and moisture levels. Both these involve incubation of starch at temperatures between the glass transition temperature and GT. HMT is usually carried out at low moisture levels (<35%) whereas ANN is done in excess of water (>60%) or at intermediate water levels (40-55%)[64]. Literature shows uncertain relationship between HMT and rice starch digestibility with HMT having greater, lower or no effect on digestibility. A higher value of digestibility was demonstrated in heated waxy starches than in non-heated samples[65]. Similarly, autoclaved HMT rice starches showed higher digestibility than their respective native starches[66]. On the contrary, decreased RDS and increased SDS and RS contents were observed in HMT rice starches[48,49] and heated flours[67]. Chang *et al.*[50] reported that RS and SDS contents were enhanced to 10.4 and 45.8%, respectively by combining HMT with parboiling. The rate of starch digestibility in HMT rice was lower than that of steamed rice[68]. Anderson *et al.*[65] reported that HMT showed no effect on waxy or non-waxy type of rice starches. Longer duration of heating (60 min *vs.* 30 min) during HMT has been shown to increase digestibility[65,67] due to formation of RS[67]. But an extended heating period of 8 hours was shown to reduce the RS content in waxy rice starch in comparison to native starch[52]. Decrease in RDS with increase in RS has been found in HMT starches with high, medium and low amylose content and is assumed to occur because of interactions between amylose and amylopectin formed during HMT[69]. However, contradictory results reporting reduction in RDS levels in HMT waxy starches along with reduced RS levels were found in another study[52]. This might be because waxy starches lack amylose and have lower proportion of long chain amylopectin[70]. Moisture content is also reported to influence the extent to which HMT affects digestibility. HMT starches prepared by autoclaving at different moisture levels (15/20/25%) had more susceptibility to α-amylase, and susceptibility increased with increase in moisture levels[66]. On the contrary, starch digestibility was shown to decrease asmoisture content in samples increased (10/20/30%)[49]. ANN treatment alone and ANN-HMT combined treatments have reports to influence the rice starch digestibility. ANN treated rice starches were more digestible by α-amylase[51] as well as elevated RDS and reduced SDS and RS levels[52]. This was ascribed to an increase in porosity of granules and reduced crystalline structure which both facilitates enzyme accessibility to starch[52]. In one study, treatment with a combination of ANN and HMT enhanced the RDS and SDS levels and reduced RS levels in waxy rice starch, which was probably due to disruption of crystalline structure by HMT[52]. Other studies on acid treated rice starch reported an increased RS content due to ANN treatment[64] and ANN-cross-linked starch[71]. Since HMT and ANN do not arrive at GT, partial gelatinization could be an important factor driving digestibility.

Chemical modifications like acetylation using acetic anhydride in modified food starches has observed with higher contents of type 4 resistant starch (RS4)[53]. Physically (HMT) and chemically (citric acid) modified in order to low digestible starch having higher proportion of RS3/RS4 were reported[55]. Production of RS from rice by dual autoclaving-retrogradation treatment with understanding structural and digestibility features were analyzed[56]. Thus, single or double modified starches possess enzyme resistant properties. It has been reported that acetylated, hydroxypropylated and cross-linked starch reduced the extent of enzyme-catalyzed hydrolysis. The 4-α-glucanotransferase (4-α-GT) treated starch samples showed an increase in slow digestion property compared to control starch[57]. About 10-20-fold increase in RS content was observed in 4-α-glucanotransferase treated starch[58].

Commercial counterparts and dietary regulations

Specialty starches are one of the key ingredients in the evolving designer food prototypes attributed with better nutritional and functional quality. Demand for bio-functional foods of low glycemic profile including low digestible starch market revenue is projected to reach about $12 billion by 2025. High RS containing starch, named as RS-rich powder is commonly used in bio-functional foods due to various functional and textural attributes like low calorie value (0.25 kcal/g), bland flavour profile, low water binding capacity, process tolerance to extreme pH and temperatures. Majorly the processed RS forms like RSIII and IV has got developed as well-known functional ingredient brands like ActiStar® 11700 resistant starch (Cargill, Minneapolis, USA), HIMAIZE 260 (Ingredion Incorporated, Westchester, Illinois, USA) and NOVELOSE 330 (Ingredion Incorporated, Westchester, Illinois, USA) are RSIII type. Few RSIV type like Fibersym RW/FiberRite RW (MPG Ingredients Inc., Atchison, Kansas, USA) with about 85% total dietary fibre are also commercially used. These are modified starch cross-linked with sodium trimethaphosphate. These starches majorly used as partial replacement for major ingredients like wheat flour in bakery products due to their low swelling capacity with optimal water retention. Very few IRS products are in market, among which high amylose maize starch, Eurylon, (Roquette America Inc., USA), having 83% RSII used as functional ingredient was observed with delivering better textural properties. High amylose (HA) maize starch, HylonVII, (Ingredion Incorporated, Westchester, Illinois, USA) with 53% RSII was reported to improve the farinograph properties and bread quality[72]. HYLON VII is a RSII type, obtained from high-amylose hybrid corn with RS content of 70%. They have commonly used as thickening agents, for stronger gels and films[73]. Green banana Starch by Natural Evolution (Walkamin, Queensland, Australia) is another product with about 42% RSII which decreased the digestibility and glycemic spike[74]. Green plantain flour, Chiquita with 50% RSII improved functional quality of gluten free breads[75].

In general, inherent resistant starch (IRS) types are physiologically alike; they are soluble, fermentable, and nutritionally more similar to non-starchy polymer

(NSP) than to digestible starch[76]. Commission of the European Communities (2008) defines 'dietary fibre' rather 'IRS' as a carbohydrate polymer with three or more monomeric units, which are neither digested nor absorbed in the small intestine. Expert committees to place dietary guide lines are generally based on their assessment on a number of sources of information, including consensus documents; evidence based systematic reviews, research studies and recommendations by expert panels. Regularity authorities also take into accounts the draft recommendations and comments from stakeholders, including the public and private institutions. Apart from the potential health benefits RS also lowers impact on the sensory properties of food compared with traditional sources of fibre, as whole grains, fruits or bran. The importance of RS as a dietary fibre has been recognised globally by various health authorities[77] (IOM, 2002). As such, recommendations for fibre intakes featured in National and International dietary guidelines, but their recommendations differ among Countries at the global scenario depending upon food habits and sources of dietary fibres[78].

As per EU guidelines native starches and starches treated by amylolytic enzymes are considered to be normal ingredients rather than food additives (European Parliament, 2008). European Food Safety Authority (EFSA) as part of a novel food application (EFSA Panel on Dietetic Products Nutrition and Allergies, 2010b) assessed a type of chemically modified starch (RSIV) deemed safe and non-allergenic even at 15% level of intake in the diet. Studies on both lower and higher doses of RS ranging up to 100 g/day have been reported in varied gastrointestinal symptoms and diarrhoea like situation at higher doses[79]. EFSA in 2016, suggested re-assessment of certain starches and celluloses, including types of RSIV (hydroxypropyldistarch phosphate and acetylated distarchadipate), regarding establishment of dietary safety. Initially dietary guidelines were set by Australian expert committee keeping Australian population in mind, which were adopted by the New Zealand Government also. Later, in a workshop held in 1997, proposal came to construct an expert committee consisting eminent scientists from both Australia and New Zealand for the wider acceptance of these dietary guide lines across the population of both the countries. Further, in 2006, the first complete set of recommendations/values was published by Food Standards Australia New Zealand (FSANZ) (NHMRC, 2006). According to FSANZ dietary fibres are the edible fractions of plants and their extracts including synthetic analogues resist the digestion as well absorption in the small intestine. These fractions are usually partially or completely fermented in the large intestine consists of RS. Recommendation released for the benefit of UK population was solely based on non-starch polysaccharide's effect on bowel health, while Australian and New Zealand committee considered other health outcomes considering dietary fibre as per National Nutrition Survey of Australia (1995) and New Zealand (1997). The values for dietary fibre intake were suggested higher for both males and females of any age group. In addition, values for RS component were recommended slightly higher than 4 g/day and slightly less than 3 g/day for men and women, respectively. This dietary recommendation having special mention of the RS was the first guidelines at national level and values were considerably more than the UK recommendation which may be accounted for the differences in methodology adapted to some extent (Englyst in the UK, compared with AOAC). As per these guide lines to stick for average IRS intake, we should require a substantial increase in intake of additional vegetables, legumes and fruits in the diet. In other way round we should encourage the incorporation of high-fibre food ingredients, such as RS.

Australia's Common wealth Scientific and Industrial Research Organisation (CSIRO) evaluated its own independent assessment on dietary suggestions, and has recommended ~20 g/day intake of RS amounting 4 times higher than that present in a typical western diet[80]. The revision was made in 1993 regarding dietary recommended values (DRVs) for the United States and Canada and a comprehensive set of DRVs was published in 2005 related to nutrient intakes by a healthy US and Canadian individuals and populations. Finally, a modified definition for dietary fibres was placed forth consists of those carbohydrate components also which were not included by AOAC analysis, for example RS fractions and oligosaccharides (FNB, 2001). Recommendations given by FNB (2005) included two times higher fibre intake as compared to Americans consumes; American men eat 16.5-17.9 g/day of fibre, and women consume 12.1-13.8 g/day of fibre (AOAC measurements). These values were found substantially more as compared to the recommended intake values in the other developing countries, specifically for kids, while UK does not have any guideline for children. At present, Netherland's guide lines (HCN, 2006) have been adopted globally regarding the importance of fibre for its protective effect with reference to the Canada Institute of Medicine and USA guidelines. Apart from adoption of centralised European policies, dietary intake recommendations were given by European-wide information councils and by Pan-European expert committees also with the aim to promote nutrition and health in accordance to EU health-promotion programme. Experts working in this project recommended 25 g of dietary fibre intake per day[81], where specific type of the fibre was not specified and the figure recommended matched well with the AOAC recommendations (FAO/WHO report from 1998).

The scenario around the world regarding recommended dietary allowances (RDA) of RS/dietary fibre intake in terms of its absolute value and form has a vast difference and at the moment developing economies like India is not having its own RDA recommendations for IRS intake and is following the recommendations published by other health organizations. Average RS consumption in developed nations (Northern Europe, Italy) ranges between 3-6 g/day[82], while for Australians[83] and Americans, it is 8.5 g/day, while Indian and Chinese diets include around 10-15 g/day. Highest consumption of RS (38 g/day) is reported in the diets of rural black South Africans. Research analysis indicates that intake of up to 40-45 g/day RS is tolerable and beyond this limit digestive system might show diarrhoea and stomach bloating symptoms due to increased fermentation in colon by gut microbiota. Responses of the digestive system varies towards the types of RS or SDS and its adaptability increases over the time of consumption.

Thus, understanding the basic mechanism of starch bioavailability as well as newer in house strategies[84]. for lowering its bioavailability will assist in the ultimate goal of developing food of low glycemic amplitude. Many more identifying traditional low GI cereals and their inherent mechanism behind, will add value to those humble grains and will assist in fetching premium price in global market[85].

Conclusion

Glycemic response is a broader concept which includes the nature and extent of postprandial blood glucose profile. Low digestible starch offers the possibility of moderated glucose delivery to the body and thus proven to maintain the glucose homeostasis, to provide fullness as well as satiety and also a possible strategy to counteract the alarming T2DM condition. Demand for bio-functional foods of low glycemic profile including low digestible starch market revenue is projected to reach about $12 billion by 2025. Due to this trend, expanding staple cereals rich in inherent low digestible starch as well as adopting processing strategies to improve further gained attention. Industrial insights on various health and product specific benefits rely on its basic biochemistry, which are depended on its micro/molecular structure, matrix components, matrix interactions, physico-chemical, rheological and textural attributes. Various existing strategies/manufacturing practices have shown to elate the SDS or RS fractions and thus endorse its low digestibility nature in the modified food types. Even though specialty starches are available, more extensive studies are required in this direction to lay dietary guidelines in future.

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