Popular Article

e-ISSN: 2583-0147

Volume 3 Issue 3
Page: 0361 – 0365

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Resistant Starch in Food - A promise to a better health

Resistant Starch (RS) are those parts of our ingested food which are not digested by our digestive enzymes and are passed into the intestine where they get fermented. According to their digestive activities against α-amylase, RS can be of five types- RS1 (physically inaccessible), RS2 (native), RS3 (retrograded), RS4 (modified) and RS5 (amylose-lipid complex). Some of them can be digested partially after processing and cooking. RS have various beneficial effects on our digestive system, like maintaining intestinal microbial flora, restricting colon cancer, insulin level, glycemic index, etc. It also acts as a good source of fiber and enhances color and taste of food. Thus, it finds a huge application in processed food industries and healthcare sector for its unique physicochemical characteristics.

INTRODUCTION

Carbohydrate is one of the basic requirements of diet on a daily basis for normal metabolism and functioning. Our brain alone requires carbohydrates of about 100g day^{-1}. Its compromised amounts or even high intake can lead to severe metabolic diseases. Carbohydrates are the most easily available form of energy (60-78%) for our body, along with other vital requirements i.e., proteins, minerals, vitamins, *etc*. After cellulose, starch is the most abundant form of polysaccharide made up of amylose (80%) and amylopectin (20%) and it is the most abundant storage form in plant kingdom. It is a complex of α-1, 4 glycosidic linkages and α-1, 6 branch points (at every 24-30 glucose residues). Some starches are not digested by action of our metabolic enzymes in small intestine, resulting in fermentation & formation of short chain fatty acids (SCFAs) in large intestine (Elia *et al.,* 2007). Such starches are termed as resistant starch (RS). It is most available form of polysaccharide in our diet as well. Processed food industries are more focused in increasing Rapidly Digestible Starch (RDS) availability and lowering the availability of Slowly Digestible Starch

(SDS) & RS, in order to maintain the smooth bowel movement and digestion, thereby compromising with the glycemic index of food.

CLASSIFICATION OF STARCH

With respect to digestion ability, starch may be classified into three groups

1. Rapidly Digestible Starch (RDS)
2. Slowly Digestible Starch (SDS)
3. Resistant Starch (RS)

Rapidly Digestible Starch (RDS)

These starches are easily digested in our gastro-intestinal (GI) tract, fulfilling our body's glucose demands. This generally results in rapid secretion of insulin and uncontrolled intake of energy.

Slowly Digestible Starch (SDS)

This usually takes longer digestion time but it is can be completely digested within 120 minutes. Insulin is steadily released, maintaining a control over energy intake.

Resistant Starch (RS)

Its overall physicochemistry depends on the proportion of amylose and amylopectin. If the food starch is retrograded and consumed, amylopectin digestion by the amylolytic enzymes occurs faster than amylose. Resistant starch is not readily digested by animals, where it gets fermented by gut microbiota, releasing short chain fatty acids. This leads to controlled intake of energy.

Resistant Starch may further be classified into the following five types – RS-1, RS-2, RS-3, RS-4 and RS-5.

RS-1

Basically, this type of resistant starch cannot be digested as the seed retains its cell wall. The presence of cell wall makes it difficult for amylolytic enzyme to degrade them. Absence of cellulase in humans also inhibits cell wall degradation. Hence, the whole starch is transferred to small intestine. Chewing and milling process may make them suitable for digestion.

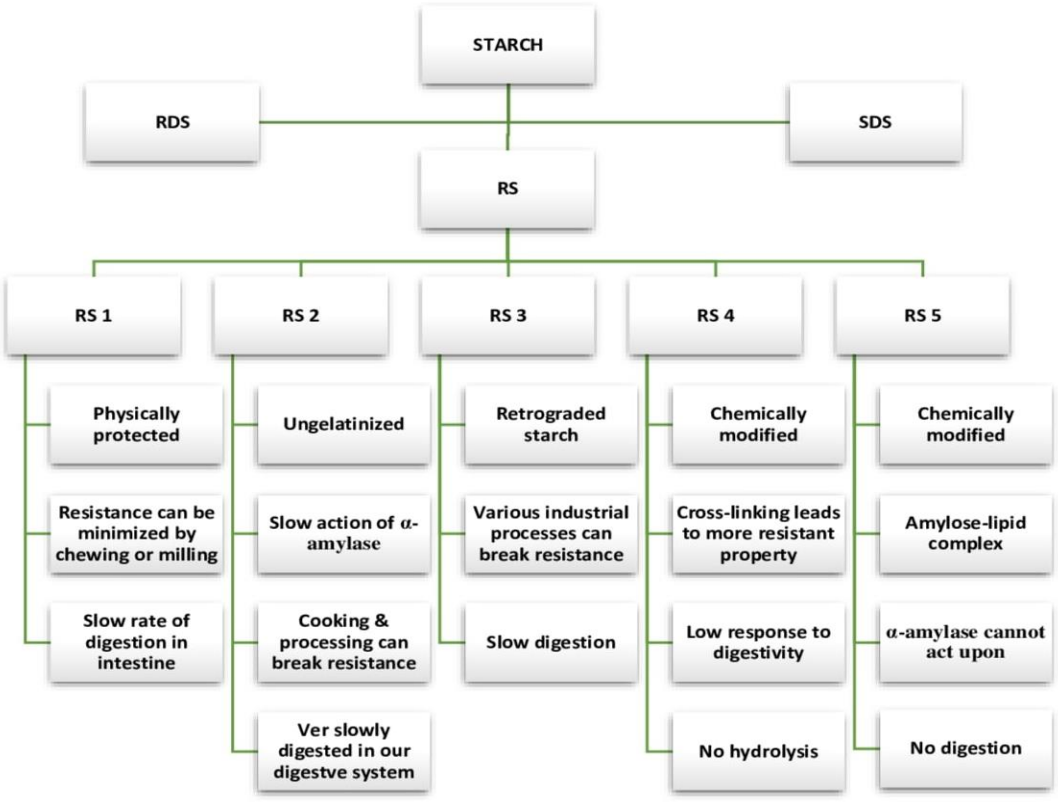

Figure 1. The classes of Starch, their behavior and nature.

RS-2

This type of crystalline resistant starch is characterized by ungelatinized behavior and slow hydrolysis. Slow digestion is due to its compact nature on which α-amylase fail to act. Cooking and processing can be chosen as options to release its resistance behavior. It may be found in unripen bananas, potatoes, maize, coarse grains, *etc*.

RS-3

It is characterized by retrograded starch formed during cooling at low temperature after being cooked, and is physically modified. Retrogradation can occur by both *in vitro* and *in vivo* methods. The crystalline and amorphous nature of this starch gel makes it difficult to be acted upon by digestive enzymes (amylolytic enzymes), causing slow digestion. Various industrial processes are available to lower the resistance of this type of starch. Cooked potatoes, cornflakes which cooled are considered under this category of resistant starch.

RS-4

Chemical modification of some starches makes them resistant to digestive enzymes and thus enzyme fail to break the α-1,4 & α-1,6 glycosidic linkages. Etherization, esterification, cross-linking with some chemicals are some options to lessen the resistant property. The more we make modifications, the more resistant the starch becomes.

RS-5

It is a result of amylose-lipid complexes which occurs during the processing of food. It has high content of amylose. It is resistant to α-amylase, compacted with unhydrolyzable straight poly- α-1,4-glucan and this is the reason for the formation of short-chain fatty acids (SCFAs), particularly, butyrate.

PROPERTIES, HEALTH ASPECTS, AND APPLICATIONS OF RESISTANT STARCH

A good amount of resistant starch can be obtained from starchy products. Many commercial suppliers are releasing their RS-based products in the markets which are based on physiological or health aspects. For instance, Neo-amylose (an RS-3 type, 87% or 95% RS) manufactured by Protos-Biotech. (Celanese Ventures GmbH) is functionally, a prebiotic which is good for intestinal health and the gut bacterial population, reducing intestinal inflammatory diseases, controlling blood glucose levels, maintaining colorectal cancer, *etc* (Sudha *et al.,* 2016). Recently, resistant starch finds great application as a raw material for the processed food industries indulged in packaged food production. Its various physicochemical properties like viscous nature, water holding capacity, gel forming abilities, *etc*. makes it suitable for a number of applications (Raigond *et al.,* 2015). Many low-calorific packaged foods available in market like potatoes, rice and wheat products which are crunchy and crispy in nature are nothing but RS-based, making them suitable for aged and diabetic

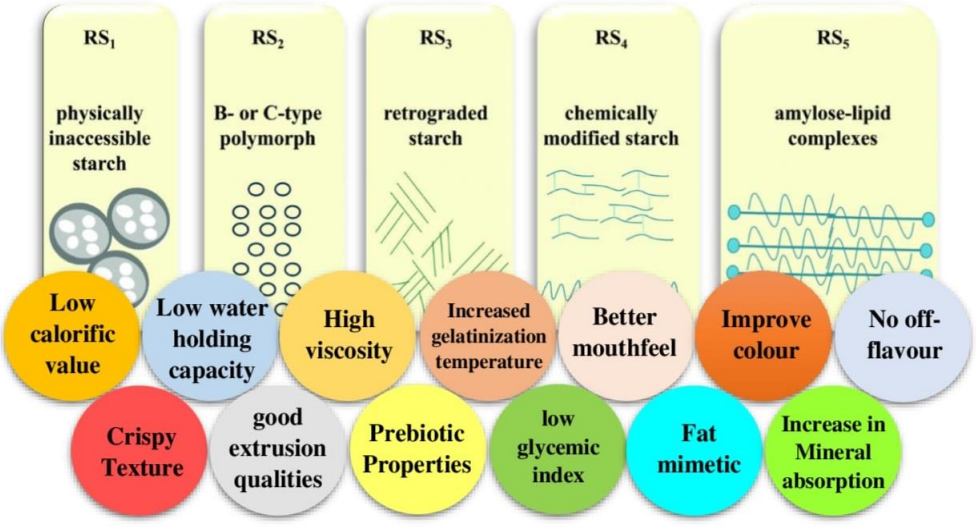

Figure 2. An overview of the structure, properties and applications of resistant starch

Table 1. Some common foods with their Glycemic Index (GI), Available Carbohydrate and Glycemic Load (GL) as per their serving size. ICMR-NIN, 2020

Foods	Glycemic index (Glucose =100)	Serving size (g/ml)	Available carb	Glycemic Load per serve
White rice, boiled	73±4	150	40	29
Brown rice, boiled	68±4	150	33	16
Boiled potatoes	78±4	150	28	14
Banana	51±3	30	20	12
Corn flakes	81±6	30	26	21
Wheat roti	66±	30	16	10
Lentils	32±5	150	17	5
Milk, full fat	39±3	250	12	3
Mango	51±5	120	17	8
Popcorn	65±5	20	11	8

consumers. An additional property of these RS-based packaged foods is their ability to form brown-reddish color, making them look attractive and fresh. Health experts and nutritionists are also suggesting RS-based foods for overall maintenance of digestive health. Being a good source of dietary fiber, gastroenterologists often suggest food which are derived or based on resistant starch so that overall need of fiber can be fulfilled. Another aspect of taking RS-based food for intestinal health is its ability to maintain the gut microbial flora by supporting their growth. It makes the intestinal environment alkaline (high pH) which favors the bacterial population balances. Reports also suggest its role in mitigating the spread of colorectal cancer. The following figure displays the various properties of resistant starch which makes it a suitable candidate for wide applications.

SERVING SIZE, GLYCEMIC INDEX AND CARBOHYDRATE CONTENT OF COMMON FOODS

Common carbohydrate containing foods such rice, wheat, banana, potatoes, *etc.* are enlisted in Table 1, where we can compare the content of carbohydrate, Glycemic Index (GI), serving size (g/ml) and Glycemic Load (GL). GI represents a number system assigned to each food to assume how much that particular food raises blood glucose after its consumption. If it is ≤ 55, it means it has low GI, a range of 56-69 indicates medium GI and a value ≥ 70 indicates high GI. High GI food is not advisable for diabetes patients. GL is a ranking system for carbohydrate-rich food that measures the amount of carbohydrates in a serving of food. Foods with a GL score under 10 are considered low-GL foods and have little impact on blood sugar; between 10 and 20 indicates moderate-GL foods, and above 20 represents high-GL foods that tend to cause blood sugar spikes. Glycemic index does not take into account the amount of carbohydrate in a food. So glycemic load is a better indicator of how a carbohydrate-rich food will affect blood sugar.

CONCLUSION

Carbohydrate is an important source of energy for regulating normal metabolism. Overconsumption of junk food in recent years is causing acute or chronic health disorders. Rising cases of diabetes and gastrointestinal disorders increased the consumption of low GI or low calorific food. Resistant starch is a very good option for health as well as industries. Being a good source of dietary fiber, it maintains growth and development of good gut bacteria. Food industries have also started recognizing the various health benefits (low calories and low glycemic loads *etc.*) and the potential of using resistant starches as raw material. Resistant starch is now commercially recognized in other industries too due to its large physicochemical properties to provide a range of options to produce goods.

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