RESISTANT STARCH: WAY TO A HEALTHY LIFE

ABSTRACT

Prebiotic polysaccharides or resistant starches (RS) are the ones that are resistant to digestion. They are not digested by pancreatic amylase and hence do not hydrolyze D-glucose into the small intestine. One of the benefits of resistant starch is that it has a good impact on digestion activity of the digestive system, bacterial flora, LDL and HDL cholesterol, blood sugar levels, and diabetes management. Swell ability, fluidity, gelation, and water absorption are some of its desired physicochemical features that make it beneficial for many foodstuffs. The development of beneficial bacteria can be promoted with the use of food supplements containing resistant starch. It functions as a prebiotic during the fermentation of fiber and feeds beneficial bacteria present in the colon of the large intestine. Multiple kinds of resistant starch exist. Their structure or source is categorized. In one food, there might be more than one resistant starch present.

In this review, we will focus on the numerous health advantages of resistant starch and how it can help to combat the obesity, diabetes, and gut problems caused by the intake of junk food.

Key words: Starch, Junk Food, Prebiotic polysaccharides, Food Supplements

INTRODUCTION

Resistant starch-containing food supplements have been used to promote the development of beneficial microorganisms. Prebiotics are bioactive substances that modify the intestinal microbiome and support bacterial development and function in the intestines that promote human

health. This has the potential to improve immune function and to give protection against illness [Leyuan *et al.* 2020] Resistant starches that are resistant to pancreatic amylase digestion are also known as prebiotic polysaccharides and hence not transformed into D-glucose in the small intestine. Modern views range from definitions to types of RS fundamental categories. There are five forms of resistant starch out of which RS1, RS2, RS3 occur naturally and RS4, RS5 forms synthetically [Sajilata *et al.* 2006 ;Birt *et al.* 2013 ; Higgins *et al.* 2013] .

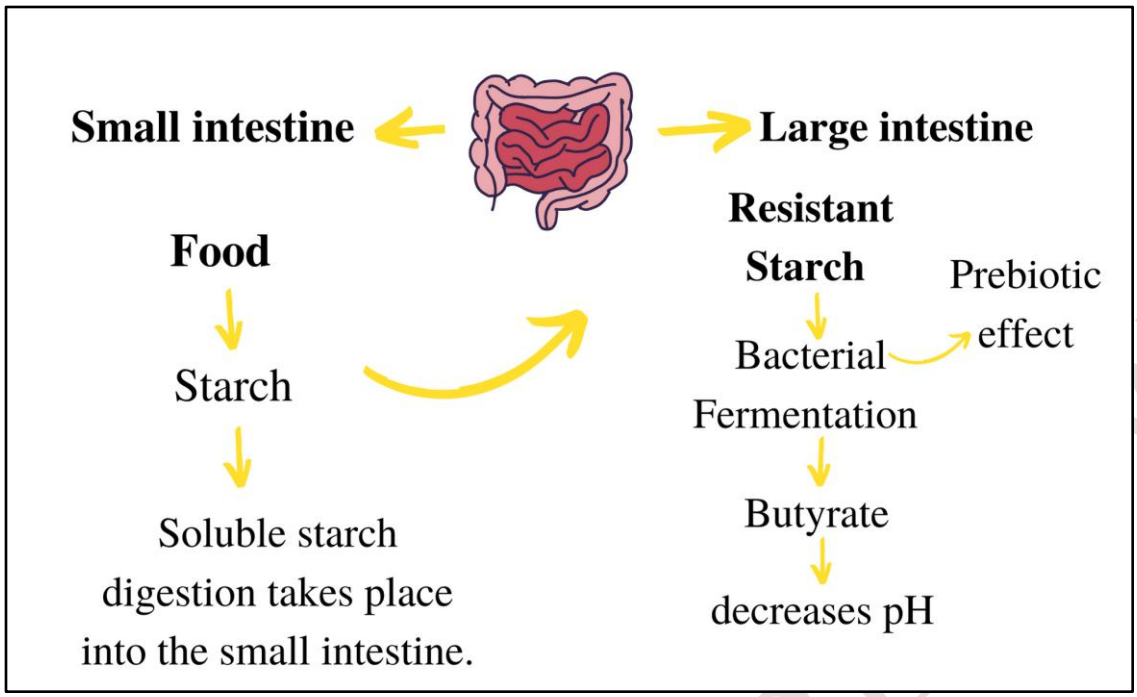
RS2-4 has been commonly examined in terms of their health consequences, whereas RS1 and RS5 studies have been less commonly investigated since they comprise dietary fibers (RS1) or lipid constituents (RS5) that might have important confounding effects. RS are capable of reaching the colon and being fermented by the gut microbiota because the small intestine can't digest it [Ashwar *et al.* 2016; Wang *et al.* 2019]. Multiple host benefit effects are related to RS when incorporated into human diets. Research findings indicate that the RS effects on the microbiome vary according to the source and kind of RS and the variances in individual intestinal microbiomes. For example, the RS4 enriched diet and RS2 enriched diet have been reported for increased *bacteroidetes phylum* with *Firmicutes phylum*, while in another RS2 and RS4 diet study, significant differences in composition have been seen in the gut microbiota of healthy human subjects. In the RS2 and RS 4 diets, for example, a substantial increase was observed. However, both forms of RS generated very comparable physiological changes [Martínez *et al.* 2010].

METABOLISM OF RESISTANT STARCH

The vast intestine microbiota ferments several forms of resistant starch (RS1, RS2, and RS3) that provide health advantages through the generation of short-chain fatty acid, higher bacterial weights, and enhancement of butyrate-producing bacteria. RS goes on and reaches the large

intestine. Resistant starch exposes and acts as food to good bacteria. Then the resistant starch breaks down, this decomposition of resistant starch gives the survival fuel for the bacteria. So, the neighboring bacteria feed on this carbohydrate molecule released by the breakdown of resistant starch and it keeps on growing. The bacteria discharge smaller molecules as trash when they feed on resistant starch. One of the body's last waste products is butyrate, which works as a fuel for the body. Butyrate gets absorbed by the large intestine. Butyrate is the favorite fuel for colon cells. Butyrate presence promotes good blood flow in the vessels of the large intestine and maintains the health of the tissue (as shown in Fig 1). Intestinal cells are vulnerable to injury and can lead to cancer, however because of Butyrate, damaged cells can eliminate themselves, and don't cause cancer. Animal research and clinical studies have identified various resistant starch properties, including altered gut flora, inflammatory mediators, and circulatory growth factors. There are various health benefits of butyrate, for example, it decreases the pH level and also It minimizes the risk of colorectal cancer and inflammation. Resistant starch feeds the colon cells by raising butyrate synthesis and leading to several advantages in the digestive system function. One of the principal reasons for improving the health of resistant starch is that it nourishes friendly gut flora and short-chain fatty acids such as butyrate are synthesized better. It was found that resistant starch is the main component of dietary supplements that promotes good bacterial growth [Brouns *et al.* 2002; Upadhyaya *et al.* 2016] .

RS does not undergo hydrolysis and is neither absorbed nor misabsorbed in the small intestine. RS possesses the property that it passes through the gut to the colon undigested/unabsorbed, where it can be degraded by microbial fermentation processes and ultimately create SCFAs as well as tiny, health-enhancing microbes [Birt D.F *et al.* 2013]. The total contribution of these amylases is to digest and absorb the majority of the starches, as indicated by the rapid rise in glucose levels after the ingestion of refined starchy foods [Wolever *et al.* 2004] , in a matter of a few minutes.



(**Figure 1**: Metabolism of resistant starch: Resistant starch feeds the colon cells by raising butyrate synthesis, leading to several advantages in the digestive system function. Butyrate presence promotes good blood flow in the vessels of the large intestine and maintains the health of the tissue. Resistant starch is the main component of dietary supplements that promote good bacterial growth.)

Resistance starch is broken down into short-chain fatty acids like propionic acid and butyric acid. Butyric acid serves as an energy source to produce beneficial bacteria residing in the large intestine [Maier *et al.* 2017]. In addition, it has been claimed that RS contributes to colon health because beneficial bacteria present in the large intestine feed on it, which results in high concentrations of short-chain fatty acids like butyrate, acetate, and propionate [Wu *et al.* 2011] .

TYPES OF RESISTANT STARCH:

Five types of resistant starch are RS1, RS2, RS3, RS4 & RS5 (*as shown in Fig 2).*

The first and foremost type which is RS1 Starch is un-accessible physically. It is called so as this is usually seen in partially milled grains and nuts form and can also be found in very dense refined starchy food. It is possible to determine RS1 as the difference between each glucose obtained from digesting enzyme structure in homogenized food samples and the glucose obtained from non-homogenized food samples. Most of the traditional foods depict the presence of this starch as it is usually heat-stable allowing the cooking operation to take place. The most common sources of RS1 are totally or partially milled seeds and grains; chewing and milling the food can subdue the effect of its resistance. [Sajilata *et al.* 2006; Anne *et al.* 2005].

Another starch type is RS2, also known as granular starch combined with the B or C polymorphs starch which is immune to enzyme digestion and is in defined granular shape. The solid structure formed by RS2 in raw starch granules limits the availability of enzyme digestion consisting of a variety of amylases and usually emphasizes the existence of an RS2 resistance like ungelatinized starch. As compared to RS1, RS2 is calculated from the difference between glucose acquired from digestive enzymes present in homogenized boiled food samples and glucose obtained from non-homogenized unboiled food samples. The similarity between the two starch types RS1 and RS2 is that their residues are partially and slowly digested in the small intestine. Raw potatoes, some legumes, bananas, and high amylose are the common sources of food containing RS2. [Sajilata *et al.* 2006 ; Anne *et al.* 2005].

Retrograded starch (RS3) is the starch fraction with the highest resistance. Amylose produced During the process of cooling gelatinized starch was primarily retrograded.RS3 is used in most moist eaten foods. Chemically, it is described as a fraction that is resistant to both boiling and enzyme digestion. It is immune to pancreatic amylase digestion. Examples of food that contain RS3 include conflicts extended or multiple times team treated food cooked potatoes which are cool overnight and then eating [Anne *et al.* 2005; Diane *et al.* 2013].

Chemically modified starches (RS4) – It is in the RS that novel chemical bonds other than alpha-(1-4) or-(1-6) are formed. This group includes modified starches obtained through various chemical treatments. Food sources for RS4 are fiber drinks, foods in which modified starches have been used (e.g. certain bread and cakes). [Sajilata *et al.* 2006 ; Anne *et al.* 2005].

Amylose-lipid complex (RS5): Amylopectin chains are formed by interacting starch with fatty acids and fatty alcohols. The helical-complex structure of the linear starch chain, coupled with the complexed fatty acid, prevents starch binding and cleavage by amylase. It is also thermally stable. For eg, high amylose starch complexed with stearic acid. [Diane *et al.* 2013].

WAYS TO INCREASE RESISTANT STARCH AMOUNT IN FOOD

Resistant starch amounts in food can mainly be increased through three ways: chemical, physical, and enzymatic processes.

Chemical Method:

The chemical method involves processes that are namely, lintnerization, oxidation, phosphorylation,acetylation,hydroxypropylation, and esterification. These processes along with their combinations help in the modification of starch granules.

Experiments involving citric acid substitution showed improvement in resistant starch content. Scanning electron microscopy of substituted starch demonstrated that the granular structure and shape had not changed. Modified starch profiles for RVA pasting revealed no peaks, indicating the cross-linking reaction. In modified starch, RS content was considerably greater, which ultimately led to a considerable decrease in the estimated glycemic index. (Rema *et al.*, 2018).

Physical Method:

The key technique in the physical technique is a series of heating and cooling. As a result of this approach, linear starch chains formed a new structure that is intolerant to hydrolysis. When cooked starch is chilled, it increases the amount of resistant starch in the rice. This method is known to promote starch retrogradation, which in turn results in higher resistant starch levels. The researchers conducted a study to determine how physical methods can influence the amount of resistant starch and the glycemic index in healthy adults by cooling rice and it was noted that cooling enhances the percentage of resistant starch considerably (Steffi *et al.*, 2015).

Enzymatic Method :

Enzymatic treatments use pullulanase and isoamylase to debranch the a-1-6 amylopectin linkages, causing the structure to be rearranged later in the retrogradation process.

An experiment was done to obtain resistant starch type III. The preparation techniques involved steam boiling after debranching with the help of isoamylase. As a result of this study, the amount of resistant starch increased in the debranched samples as compared to the unbranched samples. Moreover, it was also noted that the RS content rose as the storage time increased. (Victoria *et al.*, 2017).

HOW RESISTANT STARCH CAN IMPROVE HEALTH?

Glycemic index and resistant starch composition of commonly consumed starchy meals:

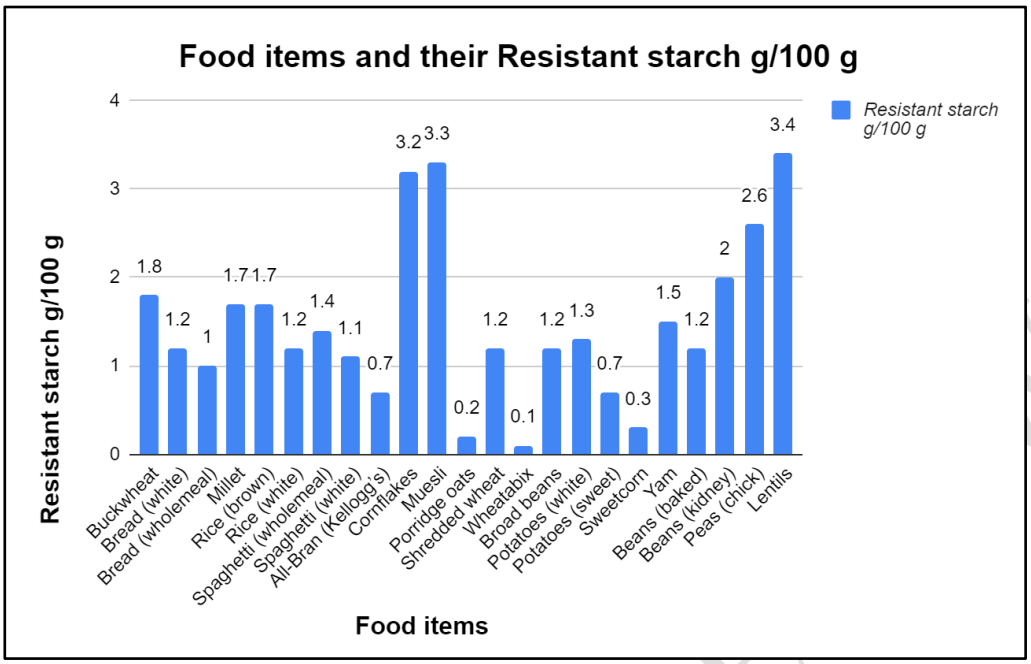


Fig.2 Food Item and their Resistant starch

[Murphy et al. 2008]

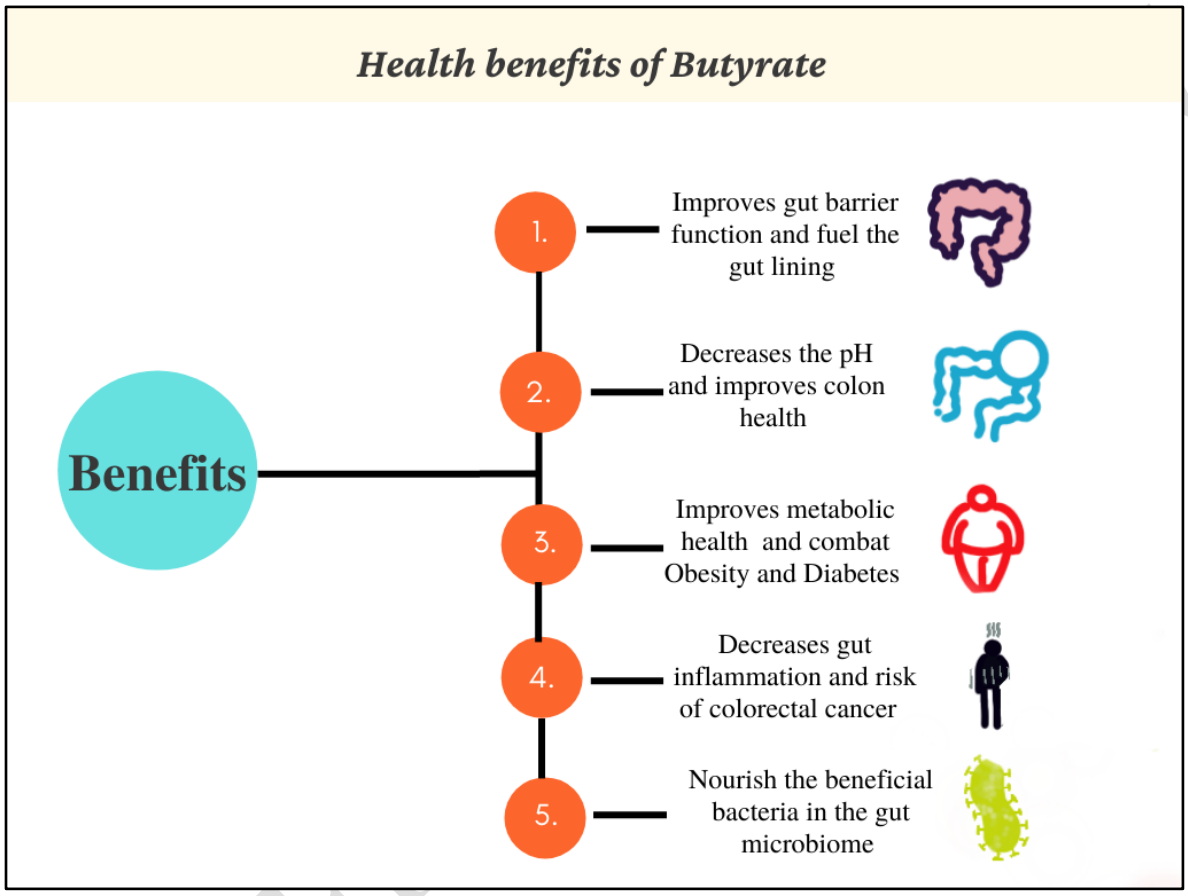
RS has been shown in various human trials to have numerous health benefits in terms of reducing metabolic syndrome and non-communicable lifestyle-related diseases in high-risk people. Some of the health-promoting effects of RS include improved insulin sensitivity of peripheral cells, continual lowering of blood glucose levels to normal limits, and reduced hunger, all of which contribute to weight loss and obesity management [Champ *et al.* 2004] .

RESISTANT STARCH'S PHYSIOLOGICAL EFFECT

Many studies have shown possible physiological effects of resistant starch like it improves Glycemic and insulinemic responses, bowel health, blood lipid profile, absorption of micronutrients (in osteoporosis); increases satiety, and reduces energy intake; it works like prebiotics.

Resistant starch helps to protect from conditions (*as shown in figure 3*) like Diabetes, insulin

responses and impaired glucose, cancer that affects the colon, inflammatory bowel disease, ulcerative colitis, diverticulitis, constipation, metabolic syndrome, cardiovascular disease, and lipid metabolism, Colonic health. It helps to cure diseases like cholera, chronic diarrhea, Obesity and can improve metabolic control and bowel health. [Champ *et al.* 2004, Brown *et al.* 1995].



*(**Figure 3**: Health benefits of Butyrate in improving digestion-related problems; Resistant starch (RS) has been found to have prebiotic and symbiotic properties. It regulates insulin and glucose metabolism and helps curb hunger and satiety.*)

HEALTH BENEFITS:

There are numerous health benefits *(as shown in Figure 4*) of resistant starch. Some of them are mentioned below:-

Resistant starch: Prebiotics and probiotics: RS was found to have prebiotic and symbiotic properties. Human and porcine SCFA profiles change when the intake of high-RS meals is increased. This suggests that autochthonous microbes are shifting, as well as a potential interaction between RS and digestive bacteria. As an aside, RS also appears to work differently from other prebiotics (such as fructooligosaccharides): when fed together, RS and fructooligosaccharides boosted fecal bacteria more than either substance once fed separately. [Higgins *et al.* 2004].

Beneficial to the treatment of various diseases and disorders: In a few studies, RS has been examined for its effect on the symptoms of inflammatory bowel diseases. Ulcerative colitis is an inflammatory colon disorder in which the colon mucosa gets ulcerated occasionally. The SCFA enemas used for the treatment of ulcerative colitis have been studied in humans, so RS could be an effective supplement to current therapies if it boosts SCFA production. According to this concept, RS has been observed (and has been used sometimes) as a cure for ulcerative colitis. This is based on producing SCFA and butyrate in vivo to cure ulcers. [Keenan *et al.* 2015].

Regulates insulin and glucose metabolism: Insulin regulates blood glucose, muscle, and fat metabolism, and helps to curb hunger and satiety. Combined with the wide range of other physiological signals, insulin influences appetite, and fat metabolism. As It takes longer for RS-rich foods to release glucose, insulin responses should be lower, stored fat can be used more efficiently, and hunger signals should be muted. They may also be helpful for the treatment of obesity and weight loss [Keenan *et al.* 2015] .

Role in the oxidation of macronutrients, satiety, and reduced weight: Researchers have observed the effects of RS on the oxidation of macronutrients and fat. They contend that consuming RS higher in a meal causes a reduction in insulin secretion, thereby increasing fat mobilization and utilization. Research has analyzed the effectiveness of RS compounds as satiety agents, which may

advantage weight-loss regimens [Slavin *et al.* 2013] .

Other health benefits: Thus, RS may enhance ileal absorption of dietary minerals depending on the type of mineral, but this benefit is unlikely to be great for humans. The role of RS in immune function has recently been revealed. It appears to play a role in the production of cytokines that promotes inflammation, such as tumor necrosis factor-alpha (TNFA) and the expression of numerous receptors on T- and B-lymphocytes and macrophages, intercellular adhesion molecule-1 [Jiang *et al.* 2020] .

Resistant Starch against Obesity

Resistant starch is one of the fascinating food that can help individuals with weight loss or maintenance through various ways:- reducing post cenal insulinemia (increase level of insulin in the blood), increasing oxidation of fat, decreasing fat storage in adipose cells, conservation of lean body mass, and increased secretion of the gut satiety peptides. Declination in basal metabolic rate (BMR) is avoided by lean body mass which ultimately decreases the total energy expenditure and thus helps in weight loss. In addition, one of the RS's properties similar to fiber elevates the thermic effect of food and also enhances the overall energy expense [Janine *et al*. 2014] .

A recent study proves that combined consumption of dietary resistant starch with protein can help in weight loss in an obese female by increasing the levels of fat oxidation, PYY, and satiety (feeling of fullness). [Christopher *et al*. 2015].

Another experiment in pigs proves that resistant starch administration reduces the energy digestibility i.e digestible energy/gross energy and metabolizability (being utilized in metabolism) along with decreasing energy intake.[Souza *et al*. 2014].

In another study, RS1, RS2, and some viscous fiber-containing food decrease the acute satiety

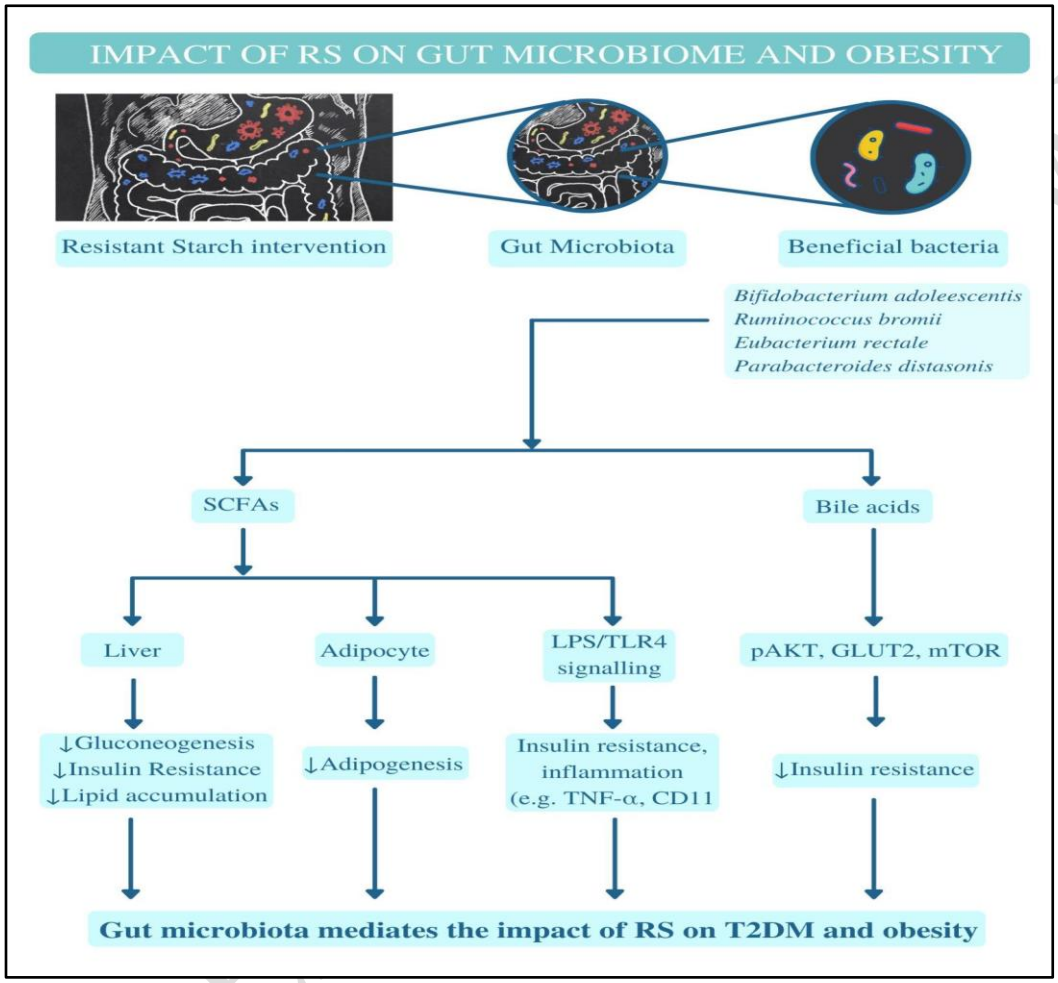
response and energy intake. However, further research is required to study the satiety response in long-term consumption of it in humans, rodents, and other animals. [Harrold *et al*. 2014] Thus RS proves to be a healthy nutrient to curb one's hunger and this fullness helps in treating obesity. Experiment on rats shows decreased levels of plasma cholesterol in combined Amylose (the main component of resistant starch) and amylopectin (low glycemic index food) fed compared to 100% Amylose fed rats (high glycemic index food); and high adiponectin concentrations and lower plasma triglycerides in RS3 fed rats. This experiment proves combined consumption of resistant starch with rice can help maintain weight. [Pawlak *et al*. 2004 ; Ha AW *et al*. 2012].

RS4- enriched flour food consumption also helps in reducing total cholesterol and non-high-density lipoprotein (HDL) cholesterol levels compared to eating daily flour food in metabolic syndrome patients. [Nichenametla *et al*. 2014].

Resistant starch also helps in reducing high levels of cholesterol and triglycerides and glycogen in the liver and increases the transcription of enzymes for hepatic lipid metabolism, cholesterol metabolism, and fatty acid metabolism, in rats. [Polakof *et al*. 2013] Furthermore, increases in gene expressions of hormone-responsive lipase, perilipin, lipoprotein lipase, and adipose triglyceride lipase were observed in rats fed RS2 fodder compared to rats fed fodder of equivalent energy density, indicating that lipolysis activity increased after feeding RS. [Keenan *et al*. 2012] In humans, RS intake resulted in a decrease in blood glucose and an increase in insulin sensitivity, but no improvement in body weight or fat mass was observed. However, no effects on visceral fat or cecum mass were reported in these human studies, so the possibility of increased cecum mass included in total body weight and reduced abdominal fat might be overlooked. [Johnston *et al*. 2010; Bodinham *et al*. 2012; Maki *et al*. 2012].

Recent evidence indicates that RS intake can minimize fat accumulation, improve insulin sensitivity, control blood glucose, and lipid metabolism, which is consistent with earlier evidence.

Recent research has discovered potential links between RS and incretins as well as the gut microbiota, suggesting that RS may be a promising food in the treatment of obesity, T2DM, and NAFLD. (as shown in fig.5) [Lei Zhang *et al.* 2015].



*(**Figure 4**: RS is a promising food in the treatment of obesity, T2DM, and NAFLD; Resistant starch is one of the fascinating food that can help individuals with weight loss or maintenance. It reduces post cenal insulinemia (increase level of insulin in the blood), increasing oxidation of fat, decreasing fat storage in adipose cells, conservation of lean body mass, and increased secretion of gut satiety peptides.)*

Health beneficial effects of resistant starch on diabetes

23% of the world population over the age of 60 have diabetes, with type 2 diabetes accounting for the majority of cases. Adults suffering from diabetes may benefit from resistant starch as it alters the gastrointestinal tract in such a way that improves health.

Experiments were done on lean Zucker rats where a few rats were fed a controlled diet while others were provided a resistant starch diet (Koh *et al.,* 2016). Although there was no change in blood glucose levels, adiponectin concentrations were found to be much higher in those who were given the diet which had resistant starch when compared to the rats who were given control diets.

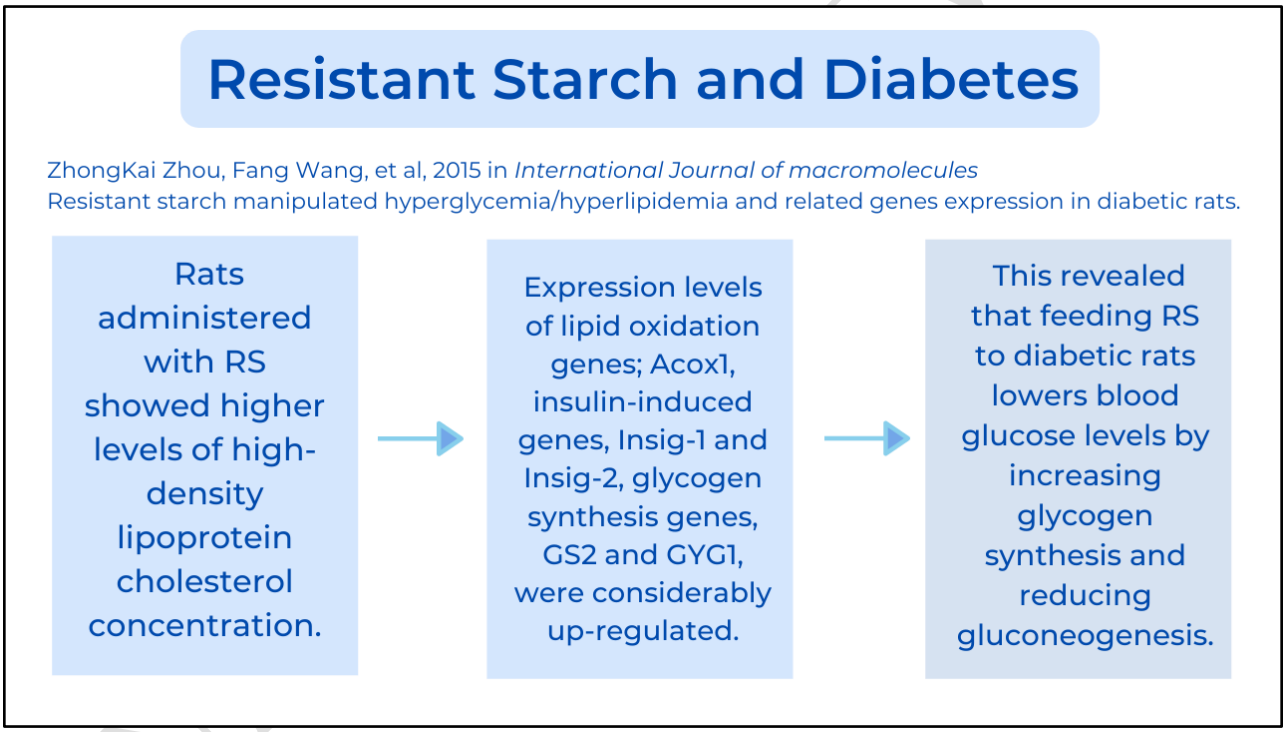
The effects of RS on oxidative stress markers and glucose control were studied through a clinical trial. The researchers noticed significant improvements in insulin sensitivity when given an RS diet. Furthermore, significant reductions were observed in insulin concentrations, HbA1c percentage, and oxidative stress indicators by the end of the trial. (Karimi *et al.,* 2016).

In a similar experiment, the researchers studied various aspects such as glycosylated hemoglobin, lipid profile, and fasting blood sugar, in women ailing from type-2 diabetes. The results showed that RS2 can play a role in enhancing glycemic control and lipid profile. (Bahram *et al.,* 2015).

In a study, the researchers reported improvement in glucose control and inflammatory indicators, indicating that resistant starch could control type 2 diabetes mellitus. They concluded that resistant starch may be an effective management tool for type-2 diabetes and oxidative stress. (Volpe *et al.,* 2016).

The results of an experiment (ZhongKai *et al.,* 2015) *(as shown in figure 6)* revealed that diabetic

rats administered with RS were found to have reduced total cholesterol levels, triglyceride levels, and blood glucose levels. On the other hand, they also showed higher levels of cholesterol concentration. Genes that are involved in lipid oxidation expression; namely, *Acox1*; insulin-induced genes, namely, *Insig-1* and *Insig-2;* glycogen synthesis genes, namely, *GS2 and GYG1*, were considerably up-regulated, according to studies of genes associated with lipid and glucose metabolism pathways. This research revealed that feeding RS to diabetic rats lowers the amount of blood glucose by improving the synthesis of glycogen and thereby reducing gluconeogenesis while enhancing lipid oxidation and cholesterol balance with higher lipid metabolism.



*(**Figure 5**: Experiment conducted by ZhongKai Zhou, Fang Wang, et al, 2015 showed that diabetic rats who were given RS had decreased total cholesterol levels, triglyceride levels, and blood glucose levels. On the other hand, they also showed higher levels of high-density lipoprotein cholesterol levels)*

Resistant starch affects gut microbiota in a way that generates starch-degrading enzymes,

promotes the synthesis of metabolites in the gut, and enhances gut barrier function to protect against Type-2 diabetes mellitus and obesity. As a result, RS with high functional characteristics can be utilized to boost the fiber content of healthy foods. (Huicui *et al.,* 2020).

The influence of high-amylose maize resistant starch or HAMRS2 on sensitivity to insulin receptors was studied. The results showed that insulin sensitivity was higher in women that were administered an RS diet. In a conclusion, in women that had developed insulin resistance, high-amylose resistant starch was linked with enhanced insulin sensitivity. (Barbara *et al.*, 2016).

Recent research studies discovered the great possible abilities of Resistant Starch as an edible compound in oral rehydration solutions and the medicating for long-term kidney disease.

Oral rehydration solution -

RS could be useful in the treatment of diarrhea and as an alternate for glucose oral rehydration solution as SCFAs produced by Resistant starch metabolism can increase liquid and Na^+ absorption in the colon (regulator of water absorption). In addition, it provides digestible glucose-rich with low osmotic properties and normal benefits of microbial fermentation.

Treatment of Kidney Disease

In renal diseases, uraemic substances (like protein, creatine, etc.) are produced in the gut and altered gut microbes composition and enhanced intestinal permeability can also be observed. SCFAs production and SCFA-producing bacteria proliferation as a result of RS consumption help in maintaining the intestine's absorbing barrier and reduced generation of waste solutes like indoxyl sulfate. [Lockyer *et al.* 2017].

Other Benefits/ Application

Resistant starch processing by acid hydrolysis and cross-linking to nano, RS4 colloidal particles can be used to manufacture dietary fiber-rich beverages.RS' bland flavor, low water-holding power, whitish color, and good viscosity stability fulfills most of the criteria of good beverage Resistant starch can also be used as a thickening agent in soap and milk products Resistant starch act as texture transformers, maintain the moisture, tenderness, and consistency of the baked foods like bread, cake, etc Resistant starch can also be used as delivery ingredients. Its excellent extrusion and film/layer/coat forming qualities are utilized to target the desired substance to the colon avoiding being utilized in the middle of the GI tract. Thus RS acts as favorable, healthy microcapsules. [Jiang *et al.* 2019].

CONCLUSION

In this review article, we have investigated that resistant starch or progressively absorbable starch maize crops are highly useful in many aspects, particularly for diabetic patients. Studies have suggested that the resistant starch gives rise to high-amylose maize starch which delivers a large range of medicinal benefits which include improvement in glycemic profile and colon wellness. When chilled, the potato starch gets resistive and becomes prebiotic, which may nourish the intestines with significant beneficial microorganisms. We have trillions of good bacteria which help in keeping the body healthy. If anyone wants to reduce weight, or have elevated blood sugar levels, digestive difficulties then it seems to be a good idea to try resistant starch. The risk of health issues and obesity can be minimized by sprinkling resistant starch over junk food. Furthermore, the addition of safe starch in the diet is a decent alternative, rather than saying completely "No" to junk food, since the carbohydrates of a safe starch make the person feel full and have no calories. In all cases, overriding fast-absorbing starch with safe starch

reduces the power thickness of the food schedule due to the low-calorie content. Many experiments demonstrated that reducing the energy thickness of regular food forms satiety and reduces weight.

Raw potato starch is white, like conventional flour powder. It contains roughly 80% of safe starch. So, every day you need simply 1–2 tablespoons. The potato starch should not be warmed down. Set out the supper and add the potato starch as the dish cools. Many people use raw potato starch to improve their eating routine to support their safe and body weight. The cook and cool method are useful to boost the strength of resistant starch in food such as rice, potatoes, pasta, etc.

Adding lentils to a portion of mixed greens or soup can decrease the risk of medical complications. Green banana flour, plantain flour, or potato starch are attempted to substitute them with incomplete flour. Safe starch gets reduced when these meals are heated or cooked. You may also enrich your food by sprinkling a modest amount of resistant starch (1-2 tablespoons). Those who want extra fiber in common foods, but don't want to change the sources of food they adore, luckily, they wouldn't have to. Manufactured using a range of maize, normal HI-MAIZE offers fiber and safe starch subtly to a wide range of dietary sources. Over 80 dispersed clinical studies showed that regular HI-MAIZE-resistant starch offers persuasive wellness advantages for stomach-associated well-being and in weight management.

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