

The Health Importance of Resistant Starch in Some Agricultural Crops: A Review



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ABSTRACT

This review included resistant starch and its health aspects due to its importance in our diet as it has enormous benefits, especially for people who suffer from chronic diseases such as diabetes, cholesterol, and high blood pressure. Moreover, resistant starch is an important component in the meals of people who follow a diet to lose weight as it has complex carbohydrates which are difficult to digest. Resistant starch is used in the prevention of intestinal inflammation and some cancerous diseases due to its ability to enhance the work of beneficial bacteria in the intestine and thus prevent colon and rectal cancer. This review provides a comprehensive overview of the physical properties of resistant starch, which include odour, colour and viscosity, in addition to its chemical composition including amylose and amylopectin, and to identify the structure and shape of the starch granule. Some methods of forming resistant starch of its five types from some plant sources such as wheat, oats, corn, rice, potatoes, legumes, etc. were also reviewed, and the possibility of increasing its percentage in these sources through a series of sequential processes such as cooking, then cooling and freezing.

Introduction

Resistant Starch (RS) is of great importance in human health, as it is like soluble dietary fibre in terms of its effect on improving the functioning of the digestive tract, the sensory properties of food, and the control of cholesterol levels. Therefore, it has received significant attention for decades [1,2]. The first person to discover RS was the scientist Englyst in 1982 AD, who used this term to describe the tiny particles of starch that resist degradation by enzymes, in addition to the multiple transactions within the body of the organism, and he defined RS as the starch that does not decompose after 120 minutes of incubation with enzymes digester [3,4,5].

RS passes through the small intestine without digestion and absorption. As a result, less of calories. It was found that RS has an essential effect in reducing the level of cholesterol in the blood, low

glucose index, obesity, and cancer diseases. Hence, RS has been of great interest in the past two decades for these health reasons. In addition, its advantages are in its effect on the sensory properties of foods [1,6-7].

Starch consumption by humans and different creatures goes back centuries. Bello-Perez and Paredes-López [8] described the physicochemical characteristics of starch in diverse food crops such as maize, pigeon pea, chickpea, and beans. In addition, non-traditional sources of starch such as bananas, mangoes, amaranth, barley, and others. The average consumption of RS in developed countries (Northern Europe, Australia, and the United States) is estimated at 3 to 6 g/day, about 8.5 g/day for Italians, and about 10 to 15 g/day for Indians and Chinese [9-12]. Therefore, it is very likely that the extreme consumption of the foods that contain starch such as (pasta and rice) is mostly in Italy, India, and China.

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Numerous researchers claimed that RS is found in traditional African food [9,13]. For instance, villagers in South Africa eat an average of 38 gm/day of RS, which consists of maize porridge and cooked beans and refrigerated [14]. Interestingly, how starch-containing foods are prepared affects their starch content, as cooking or heating destroys more RS [2,15-16].

Natural Starch Properties

1. **Odour:** Starch is colourless and odourless and may sometimes have some odours because of putrefaction during storage due to moisture or rancidity of the oil that forms starch at a high percentage, especially in grain starch. In Thailand, 20% of the banana crop was culled for non-compliance with export conditions. Therefore, this culled banana is used to produce RS type 3 because culled banana contains a large amount of RS type 2 (RS2), which is processed by autoclaving and lintnerization to produce RS type 3 (RS3), thus creating a non-rancid fish oil emulsion [17-18].
2. **Colour:** pure starch is usually bright white due to the large grains of starch and the reflection of light rays from it [15]. In some cases, the colour of the starch is pale blue, yellowish, or light red, and the reason is due to the presence of some pigments such as Xanthophyl or Carotene in the material, from which the starch is extracted. This indicates the presence of large amounts of protein, and the colour is attributed to the chemical dyes added to the industry or because of drying it at high temperatures.
3. **Viscosity:** When starch is used in the textile industry for adhesive purposes, it requires a high stickiness, which depends on the type of process to be used, for example when the sizing process is the process of dipping the yarns into a starch solution, which serves to stick the fibres of the threads together and give it strength that helps it resist tearing during the weaving process, as the starch solutions here must have high viscosity and homogeneity, while in the dyeing process, it requires a low viscosity starch [19-20]. Some researchers have studied the effect of the endogenous alpha-amylases present in wheat and rice flour on the pasting properties of starch during protease treatment [21-22].

The Chemical Composition of Starch

Scientists differ in explaining the structure of the starch molecule. The first view defines the individual construction of starch, which consists of a single homogeneous molecule. The second, more widely accepted opinion is unblemished as the poly synthesis of starch, which consists of a heterogeneous compound consisting of more than one compound. In addition, it is extracted from various natural sources, especially those that contain at least two simple compounds. For example, in seeds, tubers, grains and unripe fruits [8,23].

- **Amylose:** A compound consisting of a straight chain of D-glucose units ranging from 1000-200 units linked together by alpha 1:4 glucose bonds. Starch containing a high amount of amylose is illustrated by being more resistant to digestion and insoluble in water at low temperatures. Amylose molecules may be associated with lipids molecules in some common cereals or aromatic compounds. There is also an inverse relationship between the amylose content in starch and the gel strength and expansion, since the higher the content, the lower the strength and expansion. It can be processed by increasing the particle size [19, 24-26].
- **Amylopectin** is a branched-chain compound that consists of glucose units linked together by an alpha 4:1 glycosidic bond, composed of short chains of 22-32 glucose units. These short chains are linked together by alpha 1:6 glycosidic bonds. Amylopectin gives the starch granules assembled in the grains a semi-crystalline feature that can be seen with a light microscope [3,18, 27].

Some scientists believe that starch consists of more than two compounds. The percentage of amylose and amylopectin varies according to the different starch sources, as the ratio of amylose in most types of starch ranges between 15-30%, while the percentage of amylopectin ranges between 85-70%. There are abnormal cases, as in hybrid corn, where the proportion of amylose rises to a massive extent. It reaches approximately 60-70%, while it does not exceed in corn types of the waxy kind. The proportion of amylopectin rises to 99-98%. Amylopectin is used in textile sizing applications as a component of starch, as it increases the rigidity of the product through the crystalline rearrangement of starch [12,28,29].

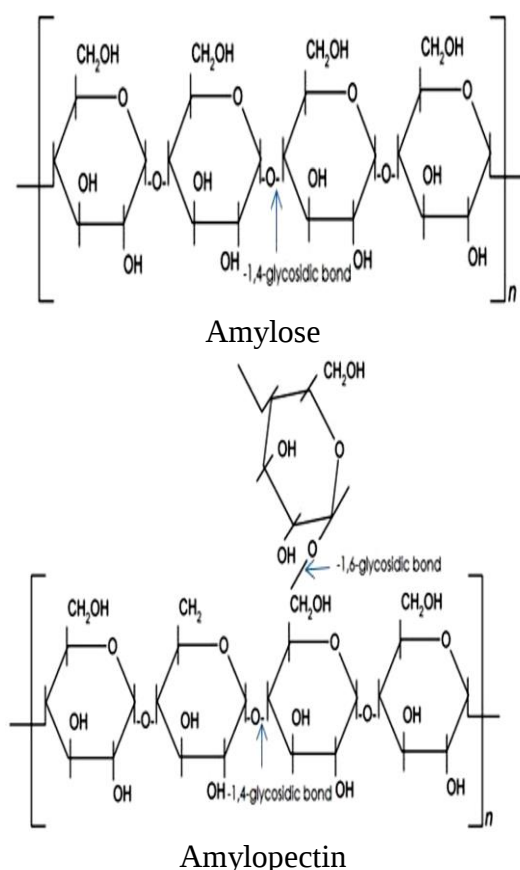


Figure 1: Chemical structure of amylopectin and amylose [30].

Starch Granule

Starch granules are found in many plant cells and vary in size and shape depending on the type of plant cell and the environmental condition under which a crop was grown. Rice and corn starch usually have angular (polyhedral) granules; Potato starch contains oval-shaped granules [31]. Wheat starch consists of round, spherical and flat granules(lens) [32]. Starch granules are distinguished by their presence in an area called hilum surrounded by starch layers representing the Maltese cross's centre in polarized light microscopy. A single starch granule may contain one hilum, called a simple starch granule or more than one hilum, called a compound starch granule, in which the layers of starch gather around each hilum independently. These layers may assemble around the navel in a non-independent way; thus, it is called a semi-composite. The location of this helium varies from one plant cell to another, either concentric like the starch grains found in maize, or off-centre like sweet potatoes. It also differs in shape, whereas spherical

or in the form of a branched slit, as in legumes [29,33-35].



Potato starch



Wheat starch



Rice starch



Mize starch

Figure (2): The different sources were obtained from starch grains [36]

Types of Resistant Starch

RS is included as a basis in our diet in appropriate quantities, such as whole grains, potatoes, legumes, and green bananas, in addition to genetically modified corn starch to increase the amount of RS in it [37] and it has several types:

(RS1): Kraithong, *et. al.* [38] showed that the protective barriers of RS1 have a vital role in controlling the hydrolysis of starch and the spread of some diseases, as it works to limit the extension of glucose release and absorption and thus control

blood sugar. RS1 is present in the coarse parts of whole grains (seeds and legumes) and is considered outside the scope of our diet since our digestive system lacks the enzymes that break down this type of starch. Therefore, these grains are usually subjected to heat treatment to alter their starchy structure [39-40].

(RS2): It is the one that resists digestion by enzymes, so it passes without digestion into the large intestine, due to the natural shape of the starch granules, which prevents these enzymes from breaking it down and affecting it. An example is starch in corn (*Zea mays*) and fresh green bananas (*Musa sp.*) [41-42].

(RS3): The starch has been exposed to heating and left to cool, such as the potato when boiling and leaving it to cool. This is known as the retrogradation phenomenon, which reshapes the amylose and amylopectin molecules of starch to produce a complex starch due to the exit of amylose chains. As a result of their explosion, the infrastructure of starch granules, and thus their resistance to digestive enzymes, leads to their arrival in the large intestine without digestion [42,2]. RS3 has health benefits such as improved lipid and cholesterol metabolism, reduced risk of colon cancer and pre-biotic effects [41, 44].

(RS4): It is formed in two ways: first, cross-linking: is chemically modified by manipulating the crosslinking bonds between starch molecules to make it more suitable for diverse technological uses. For instance, in the study of the ability of starch to swell when cooking, they found that the cross-linking between the molecules increased, the lower the capacity of starch swelling. Second, adding chemical derivatives [20,33]. Some researchers have chemically modified early indica rice by acetylation to produce a modified food starch with a high RS4 content [45].

(RS5): One type of thermally stable starch is complex lipid amylose formed by the interactions of amylose with fatty acids, which entangles with amylopectin molecules, thus restricting the enzyme hydrolysis and swelling of starch granules [33,46]. The results of Farideh *et al.* [26]. indicate that the modification of tapioca starch with fatty acids can form (RS5), which leads to a reduction of the peak viscosity value of the starch during the gelatinization. Moreover, Gallegos-Infante *et al.* [22] Modified starch in cassava mango crops to (RS5) to increase starch resistance and reduce starch digestibility.

Isolated Resistant Starch

It is used to increase the dietary fibre content of foods, as (RS2) coming from high-amylose maize, and (RS3) from cassava in addition to (RS4) obtained from wheat and potatoes, these foods can withstand processing processes at varying temperatures without losing the RS content [10,34,48]. In the food industry, flour can be replaced by RS in different types of foods such as bread, pasta, cereals, and doughs, given that if the RS is used, the produced foods have similar properties to the original food such as (colour and texture). It can also be used to manufacture imitation cheese, by using it to mimic the textural characteristics of cheese. Some of them are used as food supplements [14,33].

Agricultural Crops Rich in Resistant Starch

The principle of action of RS is like soluble and fermentable fibres, as it increases the production of short-chain fatty acids, which play the highest role in the health of the digestive system and the heart. These fatty acids help prevent and treat colon cancer by protecting the DNA of colon cells from damage and death. The beneficial bacteria in the intestines feed on these acids, leading to a decrease in the pH level in the colon and thus protecting it from infections, and it can likewise improve blood sugar and insulin sensitivity, also included as an effective ingredient in the diet. as it helps in weight loss through a feeling of fullness and satiety, due to the difficulty of its digestion and its long stay in the stomach and intestines, which leads the body to consume more energy stored in the body and hence, reducing weight. The most vital foods that contain RS are:

- **Oats (*Avena sativa*):** One of the best foods that contain RS in the diet, 100 grams of cooked oats contain 3.6 grams of RS. Whole-grain oatmeal is rich in antioxidants, anti-cancer, anti-diabetic, anti-obesity, and cardioprotective properties. Allowing cooked oats to cool for several hours or overnight may increase RS even more. A study was conducted [49-50]. on starch isolated from three different types of oats placed in the Indian Himalayas, using the double purification treatment method to obtain modified food starch of type

(RS3), which can be used for domestic and industrial purposes.

- **Cooked rice (*Cedrus sp.*)** is one of the diet's main staples in most countries. When rice is left to cool, RS increases over time. Kim, *et.al.* [51] developed a simple and cost-effective method for preparing RS-enriched cooked rice using high-amylose brown rice, adding citric acid 30-40 mg/ml under 121°C for 30 minutes. Furthermore, brown rice is better than white rice because of its higher fibre content and micronutrients such as phosphorous and magnesium [52]. The treatment by rice with a high content of RS also reduced postprandial glucose and oxidative stress for patients on patients with impaired fasting glucose (IFG) or impaired glucose tolerance (IGT) or typed 2 diabetes.
- **Wheat (*Triticum aestivum*) and Barley (*Hordeum vulgare*):** provide many quantities of RS, particularly natural whole grains, as they are a great source of fibre, vitamins, and minerals, the most important of which are vitamin B6 and selenium. Some researchers explained that blended barley starch (RS4) with wheat flour reduces the pasting process. Thus, producing pasta of acceptable quality [53-55].
- **Beans (*Vicia sp.*):** provide adequate amounts of fibre and RS, as they must be soaked and heated to remove lectins and other anti-nutrients. It also contains 1-5 grams of RS per 100 grams after cooking. In addition, the proportion of RS in legumes is increased after cooking and refrigerating [56]. Good sources include (white beans, black beans, soybeans, and peas). Han, *et.al.* [57] observed that the RS in beans reduces the concentration of serum cholesterol in the blood of rats. This is shown by Demirkesen-Bicak *et.al.* [58] when they used Pullulanase treatments to increase the level of RS in black chickpeas (*Cicer arietinum L.*).
- **Raw Potato (*Solanum tuberosum*) Starch:** It is a white powder that contains 80% RS. Many people use it as a food supplement to boost the RS content of their diet. It is also used as a thickener in foods such as (juice, oatmeal, and yoghurt). Some researchers noticed a decrease in thermogenesis for healthy people five hours after eating raw potato starch because it was not absorbed in the small intestine [59]. This is confirmed by Mirshra *et.al.* [60] when they studied the proportion of RS in raw, cooked, and cooled potatoes through several

laboratory scales on the proportion of rapidly and slowly digested. They found that potato products could be improved by increasing slowly digested (sustained energy) and decreasing rapidly digested (lowed glycaemic effect).

- **Green Bananas *Musa sp.*** are a source of RS and nutrients such as vitamin B6, vitamin D, and fibre. When the banana is ripe, it converts the RS into simple sugars (glucose, fructose, and sucrose). Green banana flour *Musa cavendishii* is also a complex source of carbohydrates, mainly from RS. Tribess *et.al.* [61] found that the amount of RS in green bananas increased when dried. Das *et.al.* [62] were able to produce RS from green banana flour using the amylopullulanase enzyme.
- **Cooked and cooled potatoes (*Solanum tuberosum*)** are an essential source of RS if cooked well and left to cool. It is best to cook them in large quantities and let them cool for at least a few hours to ensure they contain large amounts of RS and have nutrients such as vitamin C and potassium. A group of researchers studied the effect of cooking methods and storage conditions on RS, amylose, and sugar constituents of cooked Indian potato cultivars. Use three processes of cooking: boiling, pressure cooking and microwaving under storage conditions (-20,4,12°C). They found that storing potatoes for 48 hours at 12°C in the microwave increases the percentage of RS. Therefore, consumers are advised to follow this method due to the positive relationship between the glycaemic index and RS, which is inversely proportional to amylose [63]. Cooked potatoes are also affected by cooking methods, as a study showed that boiled and mashed potatoes contain the highest rate of digestion, compared to raw potatoes that were not digested [15].
- **Highly resistant corn starch,** corn fibre or corn flour, is a rich source that contains high levels of RS as it can be added to yoghurt or oatmeal. Most of the commercial varieties that may contain this product are 60-40% RS, and the rest is digestible. Moreover, corn starch affects the gel structure and viscosity during the storage of yoghurt [19,43,53,64].

Resistant Starch Benefits

- Provides fewer calories than regular starch, providing the body with 2-3 calories per gram,

while one gram of regular starch contains four calories.

- Helps reduce harmful cholesterol levels in the blood and various metabolic diseases resulting from high cholesterol, obesity, and insulin resistance [37,64-65].
- Preventing colon cancer and promoting its health. A study conducted by the American Association for Cancer Research found that eating RS, which behaves like fibre, can reduce the risk of rectal cancer associated with eating large amounts of red meat [66-68].
- Reducing weight RS helps to reduce and control weight, as it encourages fat oxidation [66].
- It reduces inflammation and enhances the work of beneficial bacteria that are naturally present in the intestines, which help in treating inflammatory bowel diseases [69].
- Controlling blood sugar for people at risk of developing type 2 diabetes. Low insulin sensitivity is believed to be a major causal factor in some of the world's most serious diseases, including metabolic syndrome, obesity, cardiovascular disease, and Alzheimer's disease. RS also boosts the capabilities of the immune system [70].
- Improved loss of appetite and consequently weight loss because of reduced energy intake, as animal studies showed reduced energy intake and improved weight loss with diets high in RS [2,44,63].
- It improves the quality of food items such as pasta, bread, and dumplings. In addition, (acha&iburu) grains are used for managing diabetes in some areas of Africa. it is used to develop healthy products such as acha-bread, cookies, and sourdough [70-71].

Conclusion

A huge number of health problems have increased in recent years due to people's bad habits. Chronic diseases are the most health issues that affect children and adults, therefore, diet is recommended by health organizations across the world to prevent and tackle the diseases such as diabetes, obesity...etc. One of the most important ingredients is RS, which contains complex carbohydrates that are difficult to digest. There are many plants and food rich in RS, and it's recommended to cook and then cool it down before

consuming it to increase the percentage of RS as it has enormous benefits.

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مراجعة: الأهمية الصحية للنشاء المقاوم في بعض المحاصيل الزراعية

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الخلاصة

تناولت هذه المقالة مراجعة لأهمية النشا المقاوم من الناحية الصحية نظراً لفوائده الهائلة للأطفال والبالغين. ويعد جزء أساسي في نظامنا الغذائي، خاصة للأشخاص الذين يعانون من أمراض مزمنة مثل مرض السكري والكولسترول وارتفاع ضغط الدم. كما ان النشاء المقاوم يدخل في وجبات الأشخاص الذين يتبعون نظاماً غذائياً لإنقاص الوزن، لما يحتويه من كربوهيدرات معقدة يصعب هضمها. ويستخدم النشا المقاوم في الوقاية من التهاب الأمعاء وبعض الأمراض السرطانية لقدرته على تعزيز عمل بكتريا المفيدة في الأمعاء وبالتالي الوقاية من سرطان القولون والمستقيم. تقدم هذه المقالة نظرة عامة شاملة على الخصائص الفيزيائية للنشا المقاوم والتي تشمل الرائحة واللون والزوجة ، بالإضافة الى تركيبه الكيميائي المتضمن الاميلوز والاميلوبكتين، والتعرف على تركيب وشكل الحبيبة النشوية. كما تم مراجعة بعض طرق تكوين النشاء المقاوم بأنواعه الخمسة من بعض المصادر النباتية مثل الحنطة والشوفان والذرة والرز والبطاطا والبقوليات غيرها، وامكانية زيادة نسبته في هذه المصادر من خلال سلسلة من العمليات المتتابعة كالطهي ثم التبريد والتجميد.

الكلمات المفتاحية: النشا المقاوم، الحبيبة النشوية، المحاصيل الزراعية، السكريات المعقدة، النظام الغذائي.