Pure Appl. Biol.,14(2):531-542,June, 2025
http://dx.doi.org/10.19045/bspab.2025.140052

Review Article

A comprehensive review on resistant starch, its types, sources, application and health benefits

Riaz Hussain[1], Maria Noor[2], Soban Khalid[2], Nisa Basharat[2], Hassan Raza[3], Muhammad Sheraz Arif[4], Atika Iffat[5], Malik Faizan Shoukat[6], Rafaquat[6], Khalid Naveed[1], Hajra Zeb[7] and Abid Mehmood[1*]

1. Department of Agronomy, The University of Haripur, Pakistan
2. Department of Food Science and Technology, Government College University Faisalabad, Pakistan
3. Department of Biology, The University of Haripur, Pakistan
4. Department: National Institute of Food Science and Technology, University of Agriculture Faisalabad, Pakistan
5. Department of Agronomy, Bahauddin Zakariya University, Multan, Pakistan
6. Department of Horticulture, The University of Haripur, Pakistan
7. Department of Mathematics and Statistics, The University of Haripur, Pakistan

**Corresponding author's email: abidawan1990@gmail.com*

Citation

Riaz Hussain, Maria Noor, Soban Khalid, Nisa Basharat, Hassan Raza, Muhammad Sheraz Arif, Atika Iffat, Malik Faizan Shoukat, Rafaquat, Khalid Naveed, Hajra Zeb and Abid Mehmood. A comprehensive review on resistant starch, its types, sources, application and health benefits. Pure and Applied Biology. Vol. 14, Issue 2, pp531-542. http://dx.doi.org/10.19045/bspab.2025.140052

Received: 20/11/2024 Revised: 10/01/2025 Accepted: 21/01/2025 Online First: 25/01/2025

Abstract

Starch is a naturally occurring water insoluble carbohydrate derived from cereals, tuber crops, roots, and contributes up to 70% of the dry weight of these commodities. It contains two polysaccharides: amylopectin and amylose. Amylopectin comprises 70 – 85% of the composition while amylose makes up about 15 – 30% of the whole composition depending on plant source. Amylopectin is composed of α (1–4) glycosidic bonds with side chains at the α (1–6) hydrogen linkages while amylose is long chain polysaccharide. another form of starch, called resistant starch (RS) escapes digestion in the small intestine and ferments in the large intestine, producing short-chain fatty acids. RS is used in controlling type 2 diabetes, in the maintenance of gut health and it plays a role in weight control. The five types of RS in natural and processed foods have the following applications enhancing the general health of the public. More studies are required to investigate individual variability and the long-term impacts related to the intake of RS.

Keywords: Amylopectin; Amylose; Short-Chain Fatty Acids (SCFAs); Glycemic Management; Prebiotic

Introduction

A portion of food's starch escapes from the human small intestine's breakdown and assimilation process where it ferments to generate fats with a short chain (SCFA) in the large intestine which is referred to as "Resistant starch (RS)" **[1]**. Gases such as methane and hydrogen, and short-chain fatty acids (SCFAs) are the most significant products of fermentation **[2]**. The distinction between the total of rapidly digested starch (RDS), slowly digested starch (SDS), and total starch (TS) is the amount of chemically resistant starch. TS – (RDS + SDS) = RS **[3]**. Many starchy foods

naturally include a type of dietary fiber that is resistant starch (RS) [4].

Resistant starch (RS) is widely recognized as a type of dietary fiber and is increasingly used in functional foods [5]. Nutritionists and public health officials recognized that eating a diet high in dietary fiber has health benefits [6]. Extensive research has demonstrated that a fiber-rich diet, particularly one enriched with RS, reduces the risk of chronic diseases such as cancer, type 2 diabetes, cardiovascular disorders, and obesity [7]. The Food Nutrition Board of the Department of Medicine of the National Academies and the US Association of Cereals Chemical researchers both classify RS as a type of dietary fiber. Unlike regular starch, Resistant starch does not breakdown as quickly, and this is a crucial physiologic characteristic. RS is further divided into five categories according to the source and physical properties of the starch [8].

Various methods have been used to create foods high in resistant starch (RS). These methods

include, but are not limited to, acetylation and oxidation [9], autoclaving [10], temperature-cycled retrogradation [11], phosphorylation and hydroxypropylation [12], pullulanase debranching [13], partial gelatinization and recrystallization [14] and citric acid modification [15] annealing hydrothermal treatments [16]. The two main components of starch, amylose and amylopectin, as well as the way these molecules are arranged within the granule, determine its properties [17].

Digestibility

There are a number of factors that influence the digestibility of foods containing resistant carbohydrates including bulkiness, heating and cooling conditions, the type and arrangement of granulated starch, and partial or complete disintegration of starch granules [18, 19]. Although resistant starches are difficult to digest, breaking the food into smaller fragments or powders can make the starch more accessible for digestion in the small intestine [20].

The amylose-to-amylopectin ratio significantly impacts starch resistance. Amylopectin digests rapidly after retrogradation, whereas amylose hydrolyzes more slowly. The gastrointestinal system uses amylolytic enzymes to hydrolyze starch, and the subsequent glucose is taken up and digested in the small intestinal tract [21]. The process of hydrolysis and digestion only occurs when the starch in food is became gelatinous during heating and prepared food is consumed immediately after preparation. Initially, "resistant starch" was first introduced by [22]. To identify a tiny portion of starch that is resistant to being decomposed in vitro by α-amylase and pullulanase therapy [23]. The primary source of RS, a linear α1, 4 D-glucan molecule, is retrograded amylose [24]. The level of amylose in granular starch and its RS content are often closely linked. There are certain exceptions, though, including pea starch, which has a high RS level and a middling amylose ratio [25] for any of the four reasons resistant starch may escape digestion:

1. The very small molecular structure of certain starches results in limited access for digestive enzymes [26]. The starch found in seeds, particles, and tubers is not physically available to the digestive enzymes.
2. Some starch sources of information, such as those found in fresh potatoes, premature bananas, and high amylose maize starch. arranged in a way which renders these challenging to digest [27].
3. Retrograded starch, which resists digestion by enzymes, forms when gelatinized starch cools. This type of "retrograded" starch can be found in around 5% of baked and cooled potatoes and corn flakes, besides other meals [28].
4. Enzymatic starch digestion is prevented by chemical changes such as esterification, etherification, and cross-bonding [29].

Types of RS

Five subtypes of RS have been recognized based on its nature: RS1, RS2, RS3, RS4, and RS5 [30]. Three variants of RS were formerly classified as Resistant Strach1, Resistant Strach 2, and Resistant Strach 3, then two further types, Resistant Strach 4 and Resistant Starch 5 (Table 1), were introduced in subsequent times [31].

Table 1. Types of resistant starch (RS), food sources, and factors affecting their resistance to digestion in the colon

Type of Resistant Starch	Description	Food Sources	Resistance Minimized By
RS1	Physically safe	Whole or partially milled grains and seeds, legumes	Milling, grinding
RS2	Ungelatinized resistant granules with type B crystallinity, gently hydrolyzed by α-amylase	Raw potatoes, green bananas, some legumes, great amylose corn	Food processing and cooking
RS3	Retrograded starch	Cooked and cooled potatoes, bread, cornflakes, food products with repeated moist heat treatment	Processing conditions
RS4	Chemically modified starches due to cross-linking with biological reagent	Foods in which modified starches have been used (e.g., breads, cakes)	A smaller amount susceptible to digestibility
RS5	Amylose-lipid complexes	Foods in which modified starches have been used (e.g., breads, cakes)	Not susceptible to hydrolysis by α-amylase

RS1

Digestive enzymes cannot physically access this form of starch because it becomes embedded within the dietary matrix, such as in slightly powdered grains and seeds [32] and the grains, seeds, or tubers' finished cell walls. In these situations, starch stays inaccessible to amylolytic and digestive enzymes, and the gastrointestinal system is unable to break away cell wall components when there are enough enzymes capable of doing so [33]. Due to its stability during most cooking processes, it may be employed in a range of classic dishes [34]. As so, this kind of starch travels through the small intestine. It must be broken down to a certain degree for full digestion. Since it is heat stable, regular cooking does not cause it to degrade [35].

RS2

HAM, or high amylose maize starch, has an exceptional form of RS2 that is outstanding because it holds strong under most cooking scenarios [36]. Amylases and other digestive enzymes are unable to reach RS2 due to its compact fitness. In the small intestine, the process of elimination of RS1 and RS2 proceeds carefully but insufficiently. The process of elimination of RS1 and RS2 proceeds carefully but insufficiently. He was the first to discover that raw starches from potatoes was resistant [37].

RS3

The universal term for retrograded starch is RS3 [38]. To allow for retrogradation, the starch must first undergo the formation of gelatin and cooling in order to create RS3. The polymer chains reassociate to form double helices during degradation through the establishment of hydrogen bonds [39]. Twice helices are parallel stranded, left-handed, having 20.8 Å loops in each. Type A crystalline structure appears in

retrograded starch [40]. Amylopectin forms partially solid gels similarly to amylose. In comparison with amylose, amylopectin's crystalline structures are less stable, and their aggregation happens more slowly. These rehydrate at degrees between 55 and 70°C [41]. The degree of DP (polymerization) of amylose has an influence on the content of RS3. As DP increases, RS3 content rises as well, DP is maximum at 100 and continuing constant after that [42]. Level of one to hundred DP is needs to exist in the form of double helix [43]. Starch pastes must be melted and cooled periodically for the above method to become functional. This includes carbohydrates that have been physically altered. Foods that have been saturated produce RS3, which has a high degree of thermal stability. It is a considerable starch fraction that is thermally stable and relied on as a component in a wide range of conventional foods [44].

RS4

RS4 is starch that has endured chemical modification, such as esterification, etherification, or crosslinking. Subcategories of RS4 are further divided into four categories based on analytical methods and water solubility [45]. With a higher rate of substitution, acetylated and hydroxypropylated starch becomes more resistant to degradation [46]. There occurs a direct proportionality between resistance and the extent of chemical modification. Greater resistance to monostarch phosphate is associated with greater quantities of substitution with phosphoric acid. Starches with greater resistance to enzymatic hydrolysis have been generated by steaming the monostarch phosphate product with glycine, as rather than monostarch phosphate alone [47]. Moreover, simmering soluble starch that has been treated with glycine and saturated with iron (III) boosts its resistance to amylolytic enzyme activity. The starch granules undergo geometrical and compositional adjustments through chemical modification, which solidifies their susceptibility to amylolytic enzymes. These modifications create unnatural bonds that block enzyme access and prevent starch degradation by forming unnatural links and impeding enzyme access [48].

RS5

Amylose-lipid complexed starch, commonly referred to as RS5, forms either under controlled laboratory conditions or naturally during food preparation. High amylose starches are normally employed to create amylose lipid complexes. The sources of RS5's structure and beginning are botanical. RS5 is a polysaccharide that is resistant to α-amylase degradation and is comprised of linear polyalpha-1,4-glucan and is insoluble in water. These include the amylose-lipid complexes, non-starch polyunsaturated and simple a-amylase regulators found in starchy meals [49].

Sources

Naturally, there is an inherent amount of resistant starch in grains, nuts, seeds, and other starchy foods [50]. Foods such as cocoyam, bananas, yams, cassava, wheat, and beans contain resistant starches [51]. Moreover, maize starch incorporates the least resistant starch [52]. On the other hand, potato starch has the highest percentage of durable starch. Comparable to potato starch, tuber starches exhibit B-type crystallinity, which makes these very susceptible to the breakdown of enzymes 75% of RS was discovered in raw potato starch [53]. Legumes have higher concentrations of resistant starch and amylose than cereals. Legumes include an enormous amount of resistant starch due to C-type crystallinity, which hinders hydrolysis. Leguminous starches that have been cooked quickly retrograde, which is increasing their ability to resist digestion [54]. Among unprocessed foods, unripe bananas are the worst supplier of resistant starch (47–57%). Consuming unripe bananas is advantageous for people's health. starch concentration [55]. Powdered unripe bananas with 17.5% resistant carbohydrates and 14.5% food fiber, was originally manufactured by companies that manufacture food [56].

17.5% RS, 14.5% of total carbohydrates and 73.4% of fiber were used to derive unripe banana flour. The resistant strength of the grain is diminished when it is ground into a fine powder. Enzyme dissolution or digestion of the whole grain can be assisted by its A-type crystalline structure **[57]**. The flour category has a low resistant starch content. The two basic components of flour are amino acids and carbohydrates; fat and fiber are found in the pericardium, aleurone sections, and germ of whole grain kernels. The chemical makeup of cereal grains undergoes modification through milling and processing. It was discovered that completely cereal grains have five times more RS than flours **[58]**, while resistant starch level in oats declined from 16 to 3% after warming up, it dropped from 12 to 5% in cooked rice during grinding **[59]**.

Applications

Resistant starch (RS) has garnered significant interest among food manufacturers and nutritionists due to its dual benefits: physiological potential and unique functional properties that enhance the production of high-quality food products. The first is the physiological potential that has been observed, and the second is the special practical characteristics that lead to the manufacturing of high-quality products **[60]**. A broad range of food items might profit greatly from resistant starch's more effective physicochemical qualities, which include swelling, increased consistency, development of gels, and water-binding ability **[61]**. RS's moderated water retention capacity contributes to better-quality end products by preserving moisture **[62]**. Since RS occurs naturally in an extensive range of starchy goods, it can be included as a useful element. Foods enhanced with RS are gaining acceptance among consumers. Consumer demand for RS-enriched foods is rising as these products are viewed as an effective way to increase dietary fiber intake **[63]**. Thin boiling starches, or resistant starches, are a kind of starch that undergo hydrolysis. This starch's high concentration along with its ability to solidify into a gel that may be applied as a low-viscosity paste are its benefits. One of resistant starch's main industrial uses is in the creation of food items that are moisture-free. RS can be used as a source of fiber in food items including bread, bread muffins, and breakfast cereals. Application evaluations executed by **[64]** shown how resistant starch modifies texture to provide the crumb with the desired degree of crispness or softness. When the RS value3 was used in baked goods as a lower energy substitute for flour, it generated results that were most identical to those obtained with control wheat flour, consisting of biscuit expand, a golden-brown hue, surface fissures, and an attractive scent **[65]**. Certain saccharides in food are rendered less accessible by RS preparations, although this has no effect on the organoleptic qualities of food items. When components with artificially heightened RS are incorporated, the product's quality remained the same and does not decrease during baking, which has no effect on the quality of baked goods. Moreover, it has no effect on the organoleptic attributes of confections and extruded commodities **[66]**. Cross-linked starches originated from potatoes, tapioca, and maize serve their purpose in formulations that need high temperature storage, low pH storage, and pulpy texture and smoothness. It has been determined that resistant starch enhances extruded cereal and snack expansion **[67]**. When it came to the management of the dough and the rheology throughout the molding cooking process, the production of dry pasta products boosted with 15% RS had little to no effect. The enhanced pasta had the same time of cooking as the control pasta and a more robust, "aldente" texture. It additionally displayed a lighter color **[68]**. These days, a few companies generate RS rich powders making use of technology like the one created at Kansas State University, which uses a starch high in amylose that comes from hybrid maize crops **[69]**.

Health effects

1. Colic cancer prevention

When resistant starch escapes digestion in the gastrointestinal tract and reaches the colon, probiotic bacteria in the lumen of the colon ferment it, producing gases such as carbon monoxide, Carbon Dioxide and hydrogen dioxide as well as short chain fatty acids (SCFA), including acetate, propionate, butyrate, and lactate [70]. Specifically, the colonocytes make use of butyrate among them, while some short-chain fatty pass through the intestinal tract and enter the portal circulation, they are absorbed by the liver and used by the host organism [71]. In vitro studies have shown that butyrate inhibits the proliferation of cancerous intestinal epithelial cells, as it is the primary energy source for healthy epithelial cells in the large intestine. Because of this, resistant starch is particularly relevant for combating colon cancer [72]. It has also been established that butyrate increases levels of glutathione in the colonic mucosa and strengthens colonocytes' resilience to food-borne toxins and other stressors [73].

2. Hypoglycemic effects

Glycemic response, also known as glycemic index (GI), characterizes a food product's capacity to increase levels of subsequent blood glucose. The GI is estimated by dividing the area under a blood sugar curve after consuming an equivalent amount of a control food, which is often glucose or white bread, by the test food's periodic surface area under the curve as measured [74]. Although it can also occur in other conditions, hypoglycemia mostly appears as a negative impact in people with diabetes mellitus. Foods that are high in RS have a slowly rate of digestion. The reason behind the reduced insulin response and reduced Consequently, starchy foods' high levels of insulin and glucose response, as well as their potential as nutraceuticals, is the starch's inaccessibility to digestive enzymes such as α-amylase, isoamylase, and pullulanase. The goods are ranked according to how much of an influence they have on postprandial glycemia using the Glycemic Index [75]. Because of its delayed rate of glucose release and prolonged the metabolism, RS has gained considerable importance in the case of type II diabetes. Greater dietary SDS content can also support healthy living in those without diabetes and those with diabetes [76]. As customers become increasingly mindful of the connection between dietary and illness, the industry of food will be searching on creating innovative meals made with different wholegrain cereal flours and other low-glycemic items [77].

3. Energy and weight management

Due to its unique properties, resistant starch (RS) is only partially digested in the small intestine and partially released as fermentation byproducts (like acetate) in the large intestine, provide a steady release of energy over several hours after consumption. Compared to fully broken down starch, which has an energy value of 15 kJ/g (or 4.2 kcal/g), RS has a relatively low energy value of barely eight kJ/g (2 kcal/g) [78]. Compared to digestible carbohydrates based on glucose, dietary habits containing lots of RS have lower glucose response as well as fewer calories. [79] demonstrated that RS serves as a bioactive culinary additive, stimulating gut hormones that have a significant cost-effective impact. This might be an adequate natural obesity treatment technique.

4. RS encourages enzymatic probiotics

Prebiotic attributes of Resistant strach have been discovered, and prebiotic potential has received attention. "Prebiotics are defined as non-digestible dietary substances that preferentially promote the establishment and/or activity of one or a small number of distinct types of bacteria already present in the colon, hence very helpful to improve health of host. [80]. RS functions as a prebiotic component by stimulating the establishment and activity of probiotic bacteria and engaging with other prebiotic dietary fibers as β-glucans [81]. Probiotics work to encourage human health by

preventing one or more bacterial species from specifically colonizing the gastrointestinal system of individuals or animals. Because a prebiotic substance, RS increases the initial concentrations of the targeted species within the intestinal tract while shielding some of the creatures that are devoured on route. When probiotic-producing bacteria first emerge in the colon, a very small percentage of them may use RS as a substrate **[82]**. High amylose starches (HAS) are a source of RS2 and operate as a prebiotic. The way that HAS encourages the expulsion of probiotic-producing microbes in the feces is how it strengthens health. When compared to a diet high in amylopectin starch, HAS also decreases plasma cholesterol and triglyceride concentrations and reduces the establishment of irreparable insulin resistance in humans **[83]**.

5. Mineral absorption

Resistant starch may help boost intestinal absorption of micronutrients for according to many studies. Rats fed a diet high in resistant starch had higher absorption of minerals like magnesium, potassium, calcium, iron, and zinc, and copper **[84]**. Resistant starch, however, enhanced calcium absorption for individuals while having little influence on other mineral absorption. Another research reviewed the apparent absorption of minerals in the presence of resistive and digestible starches, containing calcium, phosphorus, iron, and zinc **[85]**. Research showed that, as opposed to a diet high in totally digested starch, a meal rich in resistant starch considerably improved the low iron and calcium uptake **[86]**.

6. Lowering the development of gallstones

The consumption of digestible starch increases insulin output, which in turn promotes the synthesis of cholesterol and contributes to gallstone formation. There are reports that insulin promotes the synthesis of cholesterol. As a result, the intake of resistant starch (RS) reduces the overall incidence of gallstones. In southern India, gallstones are less prevalent than in northern India since there is a higher consumption of whole grains there rather than flour **[87]**.

Conclusion

In conclusion, resistant starch is an important dietary component that has a lot of promise to enhance general health. Its advantages go beyond glucose control and include protection against chronic diseases, gut health, and weight management. Our comprehension of RS and its uses will grow, enabling us to more fully realize its potential to improve human health and wellbeing. For resistant starch to be completely utilized and successfully incorporated into the world food chain, further study and development in this area are required.

Authors' contributions

Conceived and designed the experiments: M Noor & R Hussain, Performed the experiments: S Khalid, N Basharat & H Raza, Analyzed the data: MS Arif & MF Shoukat, Contributed reagents / materials / analysis tools: Rafaquat & A Iffat, Wrote the paper: H Zeb, A Mehmood & K Naveed.

References

1. Jiali L, Wu Z, Liu L, Yang J, Wang L, Li Z & Liu L (2023). The research advance of resistant starch: Structural characteristics, modification method, immunomodulatory function, and its delivery systems application. *Crit Rev Food Sci* 1-18.
2. Noor M, Nisa Basharat MA, Naveed K, Hussain R, Arif MS, Qadir G & Mehmood A (2024). Extraction techniques and purification methods: Precision tools for pure innovation. *Pure Appl Biol* 14(2): 224-248.
3. Sajilata MG, Singhal RS & Kulkarni PR (2006). Resistant starch–a review. *Comp Rev in Food Sci and Food Safety* 5(1): 1-17.
4. Maseko KH, Regnier T, Meiring B, Wokadala OC & Anyasi TA (2024). Musa species variation, production, and the application of its processed flour: A review. *Sci Hortic* 325: 112688.

5. Mikulíková D Masár Š & Kraic J (2008). Biodiversity of legume health-promoting starch. *Starch-Stärke* 60(8): 426-432.
6. Fernández-López J, Viuda-Martos M, Sendra E, Sayas-Barberá E, Navarro C & Pérez-Alvarez JA (2007). Orange fibre as potential functional ingredient for dry-cured sausages. *Eur Food Resh and Technol* 226: 1-6.
7. Ashwar BA, Gani A, Shah A, Wani IA & Masoodi FA (2016). Preparation, health benefits and applications of resistant starch-A review. *Starch-Stärke* 68(3-4): 287-301.
8. Raigond P, Ezekiel R & Raigond B (2015). Resistant starch in food: a review. *J of the Sci of Food and Agric* 95(10): 1968-1978.
9. Simsek S, Ovando-Martínez M, Whitney K & Bello-Pérez LA (2012). Effect of acetylation, oxidation and annealing on physicochemical properties of bean starch. *Food Chem* 134(4): 1796-1803.
10. Shahzad Q, Sammi S, Mehmood A, Naveed K, Azeem K, Ahmed Ayub MH & Shokat O (2020). 43. Phytochemical analysis and antimicrobial activity of adhatoda vasica leaves. *Pure and Appl Biol* 9(2): 1654-1661.
11. Khan MJ, Qasim Ayub, IH, Mehmood A, Arif N, Mehmood S, Shehzad Q & Haq NU (2020). Responses of persimmon (*Diospyros kaki*) fruits to different fruit coatings during postharvest storage at ambient temperature. *J of Pure and Appl Agric* 5(3).
12. Sui Z, Shah A & BeMiller JN. (2011). Cross-linked and stabilized in-kernel heat-moisture-treated and temperature-cycled normal maize starch and effects of reaction conditions on starch properties. *Carb Polymers* 86(4): 1461-1467.
13. Mehmood A, Naveed K, Liu K, Harrison MT, Saud S, Hassan S & Fahad S (2024). Exogenous application of ascorbic acid improves physiological and productive traits of *Nigella sativa*. *Heliyon* 10(6): e28766.
14. Chung HJ, Liu Q & Hoover R (2009). Impact of annealing and heat-moisture treatment on rapidly digestible, slowly digestible and resistant starch levels in native and gelatinized corn, pea and lentil starches. *Carb Polymers* 75(3): 436-447.
15. Mehmood A, Naveed K, Ayub Q, Alamri S, Siddiqui MH, Wu C & Fahad S (2021). Exploring the potential of moringa leaf extract as bio stimulant for improving yield and quality of black cumin oil. *Sci Rep* 11(1): 24217.
16. Govindaraju I, Zhuo GY, Chakraborty I, Melanthota SK, Mal SS, Sarmah B & Mazumder N (2022). Investigation of structural and physico-chemical properties of rice starch with varied amylose content: A combined microscopy, spectroscopy, and thermal study. *Food Hydrocolloids* 122: 107093.
17. Bello-Perez LA & Paredes-López O. (2009). Starches of some food crops, changes during processing and their nutraceutical potential. *Food Eng Rev* 1: 50-65.
18. Ayub Q, Khan SM, Hussain I, Gurmani AR, Naveed K, Mehmood A & Hussain A (2021). Mitigating the adverse effects of NaCl salinity on pod yield and ionic attributes of okra plants by silicon and gibberellic acid application. *Italus Hortus* 28(1): 1-59.
19. Mehmood A, Naveed K, Azeem K, Khan A, Ali N & Khan SM (2018). 10. Sowing time and nitrogen application methods impact on production traits of Kalonji (*Nigella sativa* L.). *Pure and Appl Biol* 7(2): 476-485.
20. Magallanes-Cruz PA, Flores-Silva PC & Bello-Perez LA. (2017). Starch structure influences its digestibility: a review. *J of Food sci* 82(9): 2016-2023.
21. Mesta-Corral M, Gómez-García R, Balagurusamy N, Torres-León C & Hernández-Almanza AY (2024). Technological and Nutritional Aspects of Bread Production: An overview of

current status and future challenges. *Foods* 13(13): 2062.
22. Englyst HN, & amp; Cummings JH (1984). Simplified method for the measurement of total non-starch polysaccharides by gas-liquid chromatography of constituent sugars as alditol acetates. *Ana* 109(7): 937-942.
23. Bangar SP, Ashogbon AO, Singh A, Chaudhary V & Whiteside WS (2022). Enzymatic modification of starch: A green approach for starch applications. *Carb Polymers* 287: 119265.
24. Mehmood A, Naveed K, Jadoon N, Ayub Q, Hussain M & Hassaan M (2021). Phytochemical screening and antibacterial efficacy of black cumin (*Nigella sativa* L.) seeds. *FUUAST J of Biol* 11(1): 23-28.
25. Adewale P, Yancheshmeh MS & Lam E (2022). Starch modification for non-food, industrial applications: Market intelligence and critical review. *Carb Polymers* 291: 119590.
26. Salimi M, Channab BE, El Idrissi A, Zahouily M & Motamedi E (2023). A comprehensive review on starch: Structure, modification, and applications in slow/controlled-release fertilizers in agriculture. *Carb Polymers* 121326.
27. Ojogbo E, Ogunsona EO & Mekonnen TH (2020). Chemical and physical modifications of starch for renewable polymeric materials. *Mate Today Sus* 7: 100028.
28. Chakraborty I, NP Mal SS, Paul UC, Rahman MH & Mazumder N. (2022). An insight into the gelatinization properties influencing the modified starches used in food industry: a review. *Food and Biopro Technol* 15(6): 1195-1223.
29. Bhatt P, Kumar V, Goel R, Sharma SK, Kaushik S, Sharma S & Tesema M (2022). Structural Modifications and Strategies for Native Starch for Applications in Advanced Drug Delivery. *BioMed Res Inter* 2022(1): 2188940.
30. Englyst HN, Kingman SM & Cummings JH. (1992). Classification and measurement of nutritionally important starch fractions. *Eur J of Cli Nut* 46: S33-50.
31. Obadi M & Xu B (2021). Review on the physicochemical properties, modifications, and applications of starches and its common modified forms used in noodle products. *Food Hydrocolloids* 112: 106286.
32. Mehmood A, Naveed K, Khan SU, Farid A, Khan SM, Hussain Q & Fahad, S. (2024). Mitigating Adverse Effects of Salinity Through Foliar Application of Biostimulants. In *Environment, Climate, Plant and Vegetation Growth*. Cham: Springer Nature Switzerland. pp. 115-132.
33. Leszczyński W (2004). Resistant starch-classification, structure, production. *Polish J of Food and Nut Sci* 54(1s): 37-50.
34. Sajilata MG & Singhal RS. (2005). Specialty starches for snack foods. *Carb Polymers* 59(2): 131-151.
35. Hernández O, Emaldi U & Tovar J (2008). In vitro digestibility of edible films from various starch sources. *Carb Polymers* 71(4): 648-655.
36. Mehmood A, Naveed K, Muzaffar Iqbal RA, Shaukat MF, Shahzad H, Rehman AU & Haq NU (2023) Improving gas exchange characteristics, antioxidant enzymes, yield and yield attributes of black cumin through foliar application of ascorbic acid. *J of Xi'an Shiyou Uni, Nat Sci Edition* 18(10): 887-901.
37. Zięba T, Solińska D, Gryszkin A, Kapelko-Żeberska M, Raszewski B Ačkar Đ & Jozinović, A (2021). Potato starch extrusion and roasting with apple distillery wastewater as a new method for resistant starch production. *Appl Sci*11(19): 9169.
38. Gryszkin A, Zieba T & Kapelko-Zeberska M (2017). Properties of corn starch subjected hydrothermal modification. *Inter Agrophy* 31(1).

39. Wenderlein J, Kienzle E, Straubinger RK, Schöl H, Ulrich S & Böswald LF (2022). Morphology of starch particles along the passage through the gastrointestinal tract in laboratory mice fed extruded and pelleted diets. *Ani* 12(8): 952.
40. Mehmood A, Naveed K, Khan SU, Haq NU, Shokat MF, Iqbal M & Ali S (2022). Phytochemical screening, antioxidants properties and antibacterial efficacy of moringa leaves. *J of Xi'an Shiyou Uni, Nat Sci Ed*, 18(10): 59-70.
41. Ashwar BA, Gani A, Shah A, Ahmad M, Gani A, Jhan F & Noor N (2021). Resistant starch and slowly digestible starch. *Food biopolymers: Structural, Fun and Nut Prop* 19-39.
42. Nugent AP. (2005). Health properties of resistant starch. *Nut Bull* 30(1): 27-54.
43. Flint HJ, Scott KP, Duncan SH., Louis P & Forano E (2012). Microbial degradation of complex carbohydrates in the gut. *Gut Microbes* 3(4): 289-306.
44. Birt DF, Boylston T, Hendrich S, Jane JL, Hollis J, Li & Whitley EM (2013). Resistant starch: promise for improving human health. *Adv in Nut* 4(6): 587-601.
45. Raigond P, Ezekiel R & Raigond B (2015). Resistant starch in food: a review. *J of the Sci of Food and Agric* 95(10): 1968-1978.
46. Hoover R & Zhou Y (2003). In vitro and in vivo hydrolysis of legume starches by α-amylase and resistant starch formation in legumes—a review. *Carbohydrate Poly* 54(4): 401-417.
47. Masłyk E, Leszczyński W & Gryszkin A (2003). Modification-induced changes in potato starch susceptibility to amylolytic enzyme action. *Polish J of Food and Nut Sci* 53(1s): 54-56.
48. Kim MJ, Choi SJ, Shin SI, Sohn MR, Lee CJ, Kim Y & Moon TW (2008). Resistant glutarate starch from adlay: Preparation and properties. *Carb Poly* 74(4): 787-796.
49. Fuentes-Zaragoza E, Sánchez-Zapata E, Sendra E, Sayas E, Navarro C, Fernández-López, J & Pérez-Alvarez JA. (2011). Resistant starch as prebiotic: A review. *Starch-Stärke* 63(7): 406-415.
50. Charalampopoulos D, Wang R, Pandiella SS & Webb C (2002). Application of cereals and cereal components in functional foods: a review. *Inter J of Food Microbiol* 79(1-2): 131-141.
51. Van Hung P, Vien NL & Phi NTL (2016). Resistant starch improvement of rice starches under a combination of acid and heat-moisture treatments. *Food Chem* 191: 67-73.
52. Wang Q, Li L & Zheng X (2021). Recent advances in heat-moisture modified cereal starch: Structure, functionality and its applications in starchy food systems. *Food Chem* 344: 128700.
53. Bednar GE, Patil AR, Murray SM, Grieshop CM, Merchen NR & Fahey Jr GC (2001). Starch and fiber fractions in selected food and feed ingredients affect their small intestinal digestibility and fermentability and their large bowel fermentability in vitro in a canine mode. *The J of Nut* 131(2): 276-286.
54. Adeleye OO, Awodiran ST, Ajayi AO & Ogunmoyela TF (2020). Influence of extrusion cooking on physicochemical properties and starch digestion kinetics of Sphenostylis stenocarpa, Cajanus cajan, and Vigna subterranean grains. *PLoS One* 15(12): e0242697.
55. Padhi SR, Gore PG, Tripathi K, Katral A, Chandora R, Abhishek GJ & Riar A (2023). Nutritional Potential of Adzuki Bean Germplasm and Mining Nutri-Dense Accessions through Multivariate Analysis. *Foods* 12(22): 4159.
56. Buzoianu SG, Walsh MC, Rea MC, O'Sullivan O, Cotter PD, Ross RP & Lawlor PG (2012). High-throughput sequence-based analysis of the intestinal microbiota of weanling pigs fed genetically modified MON810 maize expressing Bacillus thuringiensis

Cry1Ab (Bt maize) for 31 days. *Appl and Environ Microbiol* 78(12): 4217-4224.

57. Rehman AU, Mehmood A, Naveed K, Haq NU, Ali S, Ahmed J & Shahzad Q (2022). Integrated effect of nitrogen and sulphur levels on productive traits and quality of black cumin (*Nigella Sativa* L.). *Journal of Xi'an Shiyou University, Nat Sci Edi* 18(10): 38-58.
58. Benmoussa M, Moldenhauer KA & Hamaker BR (2007). Rice amylopectin fine structure variability affects starch digestion properties. *J of Agric and Food Chem* 55(4): 1475-1479.
59. Taran SNU, Ali SA, Haq NU, Faraz A, Ali S & Mehmood A (2022). Antioxidant and antimicrobail activities, proximate analysis and nutrient composition of eight selected edible weeds of Peshawar region *Journal of Xi'an Shiyou University, Natural Sci Edi* 18(9): 517-545.
60. Kaur P, Kaur H, Aggarwal R, Bains K, Mahal AK, Singla LD & Gupta K (2024). Analysing the Impact of Resistant Starch Formation in Basmati Rice Products: Exploring Associations with Blood Glucose and Lipid Profiles across Various Cooking and Storage Conditions In Vivo. *Foods* 13(11): 1669.
61. Wang M, Zhang W, Yang L, Li Y, Zheng H & Dou H (2024). Flow field-flow fractionation coupled with multidetector: A robust approach for the separation and characterization of resistant starch. *Food Chem X*: 101267.
62. Kamal AA, Rahman TU & Mehmood A (2022). Identification, adaptability, phytochemical and nutritional potential of Slender amaranth: A review. *J of Xi'an Shiyou Uni, Nat Sci Edi* 18(9): 517-545.
63. Amin SE, Haq NU, Haider S, Shaukat MF, Arif A, Fareed A & Mehmood A (2021). Emergence and transboundry spread of lumpy skin disease in South Asian Countries: a review. *J of Xi'an Shiyou Uni, Nat Sci* 18(9): 742-766.
64. Buttriss JL & Stokes CS (2008). Dietary fibre and health: an overview. *Nut Bull* 33(3): 186-200.
65. Ayub MU, Ayub Q, Khan SM, Khan MA, Ahmad S, Hussain I & Mehmood A (2022). Pre-storage application of ascorbic acid and salicylic acid to preserve quality of peach fruits during cold storage. *J of Pure and Appl Agric* 7(4): 73-89.
66. Coudray C, Bellanger J, Castiglia-Delavaud C, Rémésy C, Vermorel M & Rayssignuier Y (1997). Effect of soluble or partly soluble dietary fibres supplementation on absorption and balance of calcium, magnesium, iron and zinc in healthy young men. *Eur J of Cli Nut* 51(6): 375-380.
67. Cummings JH & Englyst HN (1991). Measurement of starch fermentation in the human large intestine. *Can J of Physiol and Pharmacol* 69(1): 121-129.
68. Ayub Q, Hussain I, Naveed K, Ali S, Mehmood A, Khan MJ & Shehzad Q (2021). Responses of different okra (*Abelmoschus esculentus*) cultivars to water deficit conditions. *J of Hortic Sci* 16(1): 53-63.
69. Dona AC, Pages G, Gilbert RG & Kuchel PW (2010). Digestion of starch: In vivo and in vitro kinetic models used to characterise oligosaccharide or glucose release. *Carb Polymers* 80(3): 599-617.
70. Miao M & BeMiller JN (2023). Enzymatic approaches for structuring starch to improve functionality. *Annual Rev of Food Sci and Technol* 14(1): 271-295.
71. Shah SU, Ayub Q, Hussain I, Khan SK, Ali S, Khan MA & Mehmood A (2021). Effect of different growing media on survival and growth of Grape (*Vitus Vinifera*) cuttings. *J Adv Nutri Sci Technol* 1: 117-124.
72. Sun H, Fan J, Tian Z, Ma L, Meng Y, Yang Z & Nan X (2022). Effects of treatment methods on the formation of resistant starch in purple sweet potato. *Food Chem* 367: 130580.

73. Shahzad Q, Sammi S, Mehmood A, Naveed K, Azeem K, Ahmed Ayub MH & Shokat O (2020). 43. Phytochemical analysis and antimicrobial activity of adhatoda vasica leaves. *Pure and Appl Biol* 9(2): 1654-1661.
74. Bertoft E (2017). Understanding starch structure: Recent progress. *Agro* 7(3): 56.
75. Tungland BC & Meyer D (2002). Nondigestible oligo-and polysaccharides (Dietary Fiber): their physiology and role in human health and food. *Comp Rev in Food Sci and Food Safe* 1(3): 90-109.
76. Ayub Q, Mehmood A, Hayat U, Shahzad Q & Ahmad S (2020). 7. Effect of salinity on physiological and biochemical attributes of different Brinjal (*Solanum melongena* L.) cultivars. *Pure and Appl Biol* 9(4): 2190-2198.
77. Hamer HM, Jonkers DM, Bast A, Vanhoutvin SA, Fischer MA, Kodde A & Brummer RJM (2009). Butyrate modulates oxidative stress in the colonic mucosa of healthy humans. *Cli Nut* 28(1) 88-93.
78. Keenan MJ, Zhou J, McCutcheon KL, Raggio AM, Bateman HG, Todd E & Hegsted M (2006). Effects of resistant starch, a non-digestible fermentable fiber, on reducing body fat. *Obe* 14(9): 1523-1534.
79. Khan MJ, Qasim Ayub IH, Mehmood A, Arif N, Mehmood S, Shehzad Q & Haq NU (2020). Responses of persimmon (*Diospyros kaki*) fruits to different fruit coatings during postharvest storage at ambient temperature. *J of Pure and Appl Agric* 5(3).
80. Purwani EY, Purwadaria T & Suhartono MT (2012). Fermentation RS3 derived from sago and rice starch with Clostridium butyricum BCC B2571 or Eubacterium rectale DSM 17629. *Anaerobe* 18(1): 55-61.
81. Haralampu SG (2000). Resistant starch—a review of the physical properties and biological impact of RS3. *Carbohydrate Polymers* 41(3): 285-292.
82. Mehmood S, Ayub Q, Khan, SM, Arif N, Khan MJ, Mehmood A & Ayub MU (2020). Responses of Fig Cuttings (*Ficus Carica*) to different sowing dates and potting media under agro-climatic conditions of Haripur. *RADS J of Biol Res & Appl Sci* 11(2): 112-119.
83. Kolodziejczyk AA, Zheng D & Elinav E (2019). Diet–microbiota interactions and personalized nutrition. *Nat Rev Microbiol* 17(12): 742-753.
84. Muir JG & O'Dea K (1992). Measurement of resistant starch: factors affecting the amount of starch escaping digestion in vitro. *The Am J of Cli Nut* 56(1): 123-127.
85. Ayuba Q, Khana SM, Mehmood A, Haqc NU, Alia S, Ahmadd T & Shoukata MF (2020). Enhancement of Physiological and Biochemical Attributes of Okra by Application of Salicylic Acid under Drought Stress. *J of Hortic Sci and Technol* 3(4): 113-119.
86. Ebringerová A & Heinze T (2000). Xylan and xylan derivatives–biopolymers with valuable properties, 1. Naturally occurring xylans structures, isolation procedures and properties. *Macromol Rapid Comm* 21(9): 542-556.
87. Mir JA, Srikaeo K & García J (2013). Effects of amylose and resistant starch on starch digestibility of rice flours and starches. *Inter Food Res J* 20(3).