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A Review of Polyphenol-Starch Interaction on Human Digestive Enzymes, Glycemic Index, Antioxidant Properties, Physico-Chemical Properties, and Food Product Quality

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Review Article

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ABSTRACT

The effect of nourishment on human well-being has upgraded with much noticeable quality on dietary carbohydrates from long periods. The majority of the human diet is made up of cereal starch, which contains a considerable quantity of easily digestible starch. Due to the quick release of glucose in the blood, consumption of such starchy meals increases the risk of metabolic disorders, cancer, cardiovascular disease, low grade inflammation, and cognitive impairments in humans, as well as lowering comfort levels. As a result, scientists are working to reduce the glycemic index of starchy meals to suit the needs of health conscious consumers. The purpose of this study was to determine the impact of polyphenol-starch interaction on human digestive enzymes, glycemic index, antioxidant properties, physico-chemical properties, and food product quality. The majority of researchers have found that starch and polyphenol interactions in foods improve health by suppressing digestive enzymes, increasing bread hardness and decreasing bread volume, increasing peak viscosity, and reducing starch retrogradation. Because bread digests quickly, people want to eat more than their bodies require compensating for their hunger. Overeating bread increases the chance of becoming overweight, obese, and developing illnesses like type 2 diabetes. Inhibition of digestive enzymes by plant derived enzyme inhibitors is one of the most effective and promising treatments for these disorders and type II diabetes. Many researchers have examined the relevance of plant based enzyme inhibitors for diabetes control in the recent past.

Keywords: Starch; Polyphenols; Glycemic index; Antioxidant properties; Retrogradation

INTRODUCTION

Polyphenols such as anthocyanins, which are found in a variety of plant extracts, have lately attracted increasing attention due to their health-promoting properties. Earlier research has suggested that by fortifying bread with phytochemical based substances such as Green Tea Extract (GTE) under the right formulation and processing circumstances, bread of acceptable quality can be created. GTE is made up of natural tea polyphenol antioxidants and is obtained from dried green tea leaves. Tea catechins are a key component of polyphenol antioxidants. Green tea and GTE-enhanced meals are greatly appreciated by those who follow better lives because of their increasingly obvious health advantages, such as being anti-oxidative and anti-mutagenic, which contribute to a decreased risk of chronic illnesses. Green tea is one of the world's most well-known and commonly taken dietary supplements. Green tea consumption is linked to enhanced antioxidant status in the body, which may help to reduce the risk of coronary heart disease, stroke, inflammation, and cancer [1].

Because bakery goods have a high concentration of carbohydrates in their formulation, several studies have indicated that partial replacement of refined wheat flour with different ingredients such as whole barley flour and wheat bran, as well as fiber from apple, lemon, and wheat, could be easily fortified with polyphenols from selected resources as well as byproducts [2].

Previous research has looked at the impact of polyphenol fortification on the physical and sensory qualities of baked and steamed bread. Polyphenols have also been shown to reduce the activity of α-amylase and α-glucosidase, two of the most essential enzymes for starch digestion in humans. Another study found that polyphenols isolated from tea can decrease the principal activity of α-amylase, pepsin, trypsin, lipase, and other digestive enzymes. Delayed starch digestion is advantageous for generating low Glycaemic Index (GI) foods. Consumption of low GI foods can result in little variations in blood glucose levels, lowering the risk of developing type 2 diabetes mellitus over time [3].

LITERATURE REVIEW

Antioxidant capacity of polyphenols

Polyphenols are powerful antioxidants *in vitro*, owing to their low redox potential and ability to transfer electrons or hydrogen atoms. Food manufacturers have employed polyphenols antioxidant qualities to increase the shelf life of processed foods and to protect certain cysteine proteases, such as bromelain, papain, and actinidin, against sulfhydryl group oxidation. Different polyphenols show different antioxidant properties Tannic acid has antioxidant and antimicrobial properties due to its multiple phenolic groups, and anthocyanins have antioxidant capacity due to their peculiar chemical structure that can react with Reactive Oxygen Species (ROS) such as superoxide, singlet oxygen, peroxide, hydrogen peroxide, and hydroxyl radical [4].

In contrast to other dietary antioxidants like selenium, carotenoids, and vitamins C and E, polyphenols have a generally higher dietary intake. They further enhance their ability to prevent oxidative damage by chelating highly redox-active metal ions. The interactions between polyphenols and membranes may be the mechanism by which polyphenols exert their positive effects.

By adhering to the lipid head groups close to the bilayer surface and penetrating through the bilayer interface, Sirk, et al., hypothesized that polyphenols demonstrated an affinity for the lipid bilayer (absorption). Their findings demonstrated that polyphenols create hydrogen bonds with membranes, with oxygen atoms on the phospholipid acting as the hydrogen bond acceptors and phenolic hydroxyl groups as the hydrogen bond donors.

The chemical structure of polyphenols significantly impacts how effective they are as antioxidant chemicals. While phenol itself lacks antioxidant activity, ortho and para diphenolics do, and its ability to do so grows as ethyl or n-butyl groups replace hydrogen atoms in their structure. Strong inhibitors of LDL oxidation are antioxidant polyphenols, particularly flavonoids. Identified four known mechanisms by which flavonoids exercise their protective effect: Reduction of free radical formation, Protection of α-tocopherol in LDL from oxidation, regeneration of oxidized α-tocopherol, and chelation of metal ions. Polyphenols exert their preventive impact against cardiovascular disease through these antioxidant processes. Phenylacetic acids have been found to have anti-carcinogenic properties [5].

Mechanism

Antioxidants are substances that, at low concentrations, can stop free radical-mediated processes from causing oxidative damage to biomolecules (proteins, nucleic acids, polyunsaturated lipids, and carbohydrates. The antioxidant activity of flavonols has recently been linked to radicals that exhibit a planar shape that permits extended electronic delocalization between adjacent rings, according to a quantum mechanical analysis. There have been two primary hypothesized methods by which antioxidants can act as protective agents.

In the first, the free radical converts the antioxidant (ArOH) into a radical by removing an atom of hydrogen: $R^{\bullet +}ArOH \rightarrow RH+ArO^{-}$

This mechanism is referred to as H-atom transfer. ArOH functions more effectively as an antioxidant when the radical ArO- is more stable, making it less likely to react with the substrate. It is often a non-reactive phenoxyl radical due to hydrogen bonding, conjugation, and resonance. A crucial factor in assessing the antioxidant action in this mechanism is the Bond Dissociation Enthalpy (BDE) of the O-H bonds because the weaker O-H bond, the simpler the reaction of free radical inactivation will occur [6].

In the second mechanism (the one-electron transfer), the antioxidant can donate an electron to the free radical, which causes the antioxidant to become a radical cation:

$R^{\bullet+}ArOH \rightarrow R^{-}+ArOH^{\bullet+}$

The radical cation formed in this instance as a result of the electron transfer must also be stable to avoid reacting with the molecules of the substrate. These latter approaches state that the Ionization Potential (IP) is the most important energy aspect to consider when assessing scavenging activity. The electron abstraction process is made simpler by a lower ionization potential [7].

Sources of polyphenols

Polyphenols are a diverse collection of phytochemicals that contain phenol rings. Despite the extensive research on polyphenols, researchers are attempting to attract a large number of other researchers interested in discovering novel sources of phenolic compounds and their antioxidant qualities. Numerous plant-based foods, such as cereals, legumes (soybean), vegetables (especially broccoli, onion, and cabbage), and fruits (grapes, pears, apples, cherries, and various berries contain up to 200 mg-300 mg polyphenols per 100 g fresh weight), plant derived beverages, and chocolate, contain various types of polyphenols. These polyphenols, which can be extracted and purified, can be added to foods to provide nutritious ready to eat snacks. They are prevalent in both conventional and non-conventional food items. The delivery of these biologically active substances can be accomplished by using foods that have been enhanced with bioactive components. Due to their high instability, polyphenols can disintegrate when exposed to extreme temperatures, oxygen, light, enzymes, and other factors. When processing polyphenol-rich food matrices for the creation of functional matrices, such as manufactured snacks, certain circumstances must be taken into consideration. Polyphenolic substances present in plant sources have drawn more attention in recent years. This is in part because there is growing evidence that certain of them, namely the flavonoids, may have favorable impacts on people’s health [8].

One of the most common and widespread classes of plant metabolites is polyphenols, which are consumed by both humans and animals and have a wide range of biological properties, such as antioxidant, anti-inflammatory, antibacterial, and antiviral effects.

There are some health advantages associated with eating vegetables high in polyphenols, notably berries, which are small, globular fruits that range in color from red to purple.

Genetic and environmental variables both play a significant role in determining the level of polyphenols in plant based meals. The amount of plant phenol is affected by many additional parameters, including germination, degree of ripeness, variety, processing, and storage (Table 1).

New sources of phenolic chemicals have been looked into recently, in addition to wholegrain cereals and fruits. For instance, Rebey, et al., investigated the polyphenol content of cumin, a popular spice, and tiny herbaceous plant. In cumin seeds, the authors discovered 19 phenolic chemicals the main phenolic acid in cumin was p-coumaric acid, which varied from 2.33 mg/g in Indian cumin to 4.83 mg/g in Tunisian cumin. The concentrations of flavonoids ranged from 1.77 mg/g (Indian) to 2.88 mg/g (Tunisian) [9].

A wild shrub known as "murta" can be found in the southern region of Chile, particularly in the Coast Mountains and some of the pre-Andean Mountains. Although it was initially given the name "Myrtus ugni" (after the common name "Uni"), it is now more properly referred to as Ugni molinae, after Juan Ignacio Molina. Western botanics categorized and identified it for the first time in 1844. The beauty and medicinal benefits of its extracts have been passed down and used by Chilean locals for generations. Alcoholic drinks and herbal infusions are frequently used to relieve pain in the urinary system. They also have astringent, stimulating, and phytoestrogenic properties. The presence of several phenolic compounds contributes to the characteristics of extracts made from murta [10-15].

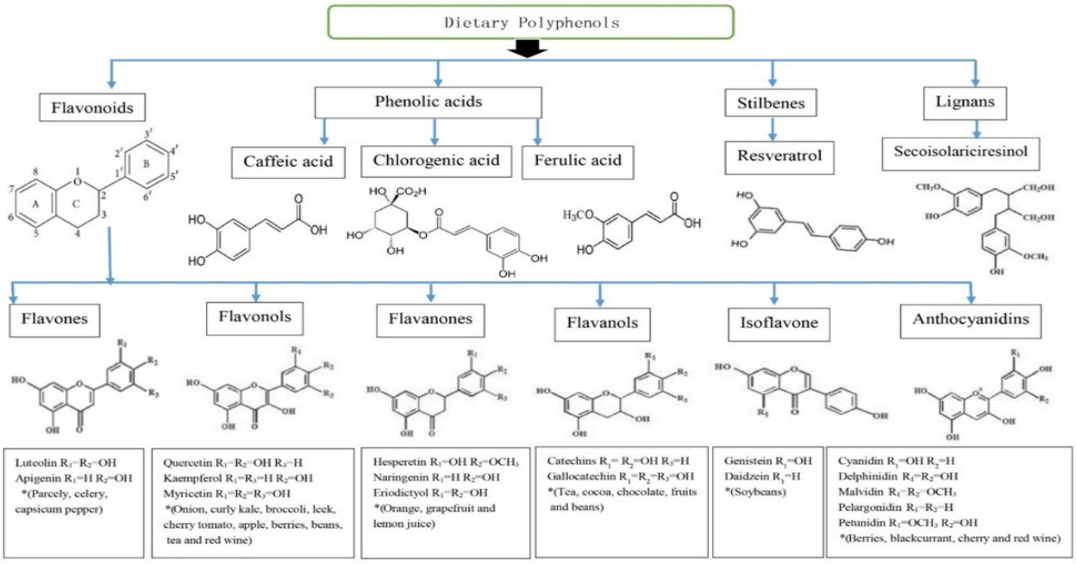
Polyphenols are classified as flavonoids, phenolic acids, stilbenes, and lignans. Flavonoids include flavones, flavonols, flavanones, isoflavones, and anthocyanins (Figure 1).

Table 1. Polyphenols are a category of plant compounds that offers various health benefits.

Polyphenols	**Source**
Anthocyanins	
Cyanidine 3-glucoside	Orange juice (1 L)
Malvidin 3-glucoside	Red wine (500 mL)
Malvidin 3-glucoside	Red grape juice (500 mL)
Cyanidine 3-glucoside	Red fruit extract (1.6 g)
Flavanols	
Epigallocatechin gallate	Green tea infusion (5 g)

Catechin	Red wine (120 mL)
Epicatechin	Chocolate (80 g)
Catechin	Pure compound
Epigallocatechin gallate	Pure compound
Epigallocatechin gallate	Green tea extract
Catechins	Black tea
Procyanidin B1	Grapeseed extract
Flavanones	
Hesperidin	Orange juice
Hesperetin	Orange juice
Naringenin	Orange juice
Naringenin	Grapefruit juice
Naringenin	Pure compound
Hesperetin	Pure compound
Flavonols	
Quercetin	Apples
Quercetin	Onions
Quercetin 4’-glucoside	Pure compound
Quercetin	Buckwheat tea
Quercetin	Pure rutin
Isoflavones	
Daidzein	Soy milk
Genistein	Soy milk
Glycitein	Soy milk
Daidzein	Pure compound
Genistein	Pure compound
Glycitein	Pure compound
Daidzein	Soy extract
Genistein	Soy extract
Daidzein	Soy nuts
Genistein	Soy nuts
Hydroxybenzoic acids	
Gallic acid	Pure compound
Gallic acid	Assam black tea
Gallic acid	Red wine
Hydroxycinnamic acids	
Chlorogenic acid	Coffee
Caffeic acid	Red wine
Caffeic acid	Red wine
Hydrocinnamic acids	Apple cider
GA: Gallic Acid; MeGA: Methyl Gallic Acid; BW: Body Weight.	

Figure 1. Chemical structures and dietary sources of different groups of polyphenols.



Importance of Polyphenols

Polyphenols contribute to the sensory and nutritive properties of plant foods to some extent. The presence of polyphenolic substances affects the astringency and bitterness of foods and beverages. Polyphenols can oxidize during processing or storage, which can provide food products with either favorable or unwanted properties. Examples of oxidative alterations that produce distinct and desirable organoleptic qualities include the browning of cocoa during processing or the oxidative polymerization of tea polyphenols during the production of black tea. On the other hand, unfavorable color and flavor in fruits and vegetables are produced by enzymatic browning processes of phenolic compounds (catalyzed by polyphenol oxidase) and nonenzymatic browning reactions [16].

Because of their unique chemical nature and ability to react with Reactive Oxygen Species (ROS) such as superoxide, singlet oxygen, peroxide, hydrogen peroxide, and hydroxyl radicals, anthocyanins are widely known for their beneficial health properties. Additionally, recent research found that anthocyanins have an inhibiting effect on digestive enzymes. McDougall, et al. The primary dietary sources of antioxidants are phenolic chemicals. Due to their ability to donate electrons, they represent a sizable group of secondary metabolites in plants and potentially scavenge free radicals. Their antioxidant action, however, is dependent on their physiologic stability, as well as the number and position of hydroxyl groups in the molecule.

People who consume diets high in plant polyphenols over an extended period may experience certain defenses against the emergence of cancer, cardiovascular disease, diabetes, osteoporosis, and neurological illnesses. Consuming foods made with whole grain cereals has several health advantages, including a higher intake of fiber. The antioxidant qualities of wholegrain cereals have also been researched [17].

This antioxidant action is related to the presence of phenolic chemicals. There are three types of phenolic acids: Free, conjugated, and bonded. Phenolic acids are one of the main classes of phenolics found in grains. The smallest portion, free phenolics, may make as little as 1% of the total phenolic acid content in wheat. Conjugated phenolic acids provide more (22% of total phenolics) than other phenolic acids. Bound phenolic acids, which have been shown to make up the majority of phenolic compounds in grains and bread made with whole grain flour, make up the remaining phenolic compounds.

The orange, red, violet, and blue hues found in nature are a result of anthocyanins, a class of flavonoids that are naturally occurring pigments in fruits and vegetables. Proanthocyanidin rich grape seed polyphenol extract has demonstrated potential for use in the treatment of Alzheimer's disease. The large intestine is affected by the chronic disease ulcerative colitis, which may be brought on by an aberrant immune response. Colon damage induced in rats was successfully treated with apple polyphenols. According to D'Argenio, et al., microscopic injury decreased by 55% and macroscopic injury decreased by 60%. It has been demonstrated that certain plant polyphenols, including flavonoids and phenolic acids, have chemopreventive activities against liver cancer [18].

RESULTS

Starch

The primary component of rice grains is starch, which is a crucial component utilized in food preparation. A plant polymer called starch is found in the endosperm of grain kernels as well as in the roots and seeds of plants. It gives people energy (4 calories per g) and is hydrolyzed to glucose, which provides the glucose required for the proper operation of the brain and central nervous system. The paper, textile, glue, food, and medicinal industries all use starch extensively. According to the degree and extent of digestion, it is categorized as Rapidly Digestible Starch (RDS), Slowly Digestible Starch (SDS), and Resistant Starch (RS) in human nutrition.

The amylose fraction of cereal starches is where lipid molecules in the form of phospholipids and free fatty acids are found. In starch granules, lipid complexes can be seen as a hydrophobic nucleus contained by amylose chain formed helices. The lipid complexes in grain starches range from 0.15 to 0.55% of the amylose fraction. Despite making up a minor portion, lipids in starch granules can dramatically limit the ability of the starch paste to swell [19].

When sorghum flour rather than pure maize starch was cooked with sorghum extracts, tannins were shown to decrease the digestibility of starch, according to Lemlioglu Austin, et al., research. However, compared to a matrix made of sorghum flour, where approximately 35% of the starch was digested after three hours and an EGI of 62, the tannins were more effective in the pure starch matrix, with about 15% digested after that time. This implies that the other endosperm components hindered tannins capacity to interact with starch but did not entirely prevent it. Starches include other substances in addition to the primary polysaccharide components, such as proteins, lipids, and phosphorus. The protein is present both on the outside and inside of the body, and its weight percentage ranges from 0.1 to 0.7%. Starches, particularly cereal starches, contain lipids (free fatty acids and lysophospholipids) in amounts of up to 1.5%. Phosphorus is found in starches as phosphate monoesters and phospholipids.

Importance of starch

There have been several recommendations made regarding the consumption of carbohydrates in the FAO/WHO expert consultation report on food, nutrition, and the prevention of chronic diseases. The report states that added sugars should be kept to no more than 10% of total energy intake, while the Acceptable Macronutrient Distribution Range (AMDR) for carbohydrates is 55%-75% of total energy intake. The Adequate Intake (AI) for total dietary fiber is 38 g for men and 25 g for women. A lot of research has been done in recent years on several innovative techniques for effectively managing blood sugar and preventing disorders associated with it. Natural compounds have evolved into a more palatable source of anti-diabetic medications when compared to synthetic drugs.

The central nervous system prefers glucose from starch digestion as a biological fuel, but it is also a signal molecule that controls gene transcription for glucose homeostasis and energy metabolism. Therefore, delaying the release of glucose from dietary carbohydrates is a useful strategy for glycemic management. The physiological effects of resistant starch, a starch fraction that cannot be digested by small intestine enzymes, include the prevention of colon cancer as well as hypoglycemic and hypocholesterolemic effects. The RS content can be utilized to identify functional foods. According to Hidayat B, et al., rice analogs made from maize processed using the granulation method are classified as functional foods with low IG values, one of which is a result of the high level of resistant starch. Wide ranging health advantages of resistant starch include the prevention of numerous illnesses such as colon cancer, diabetes, cardiovascular disorders, and obesity. Resistant starch has been prepared using a variety of techniques. These techniques include, but are not limited to, heat moisture treatments and annealing, chemical modification; enzymatic debranching, temperature cycled retro gradation and irradiation. In contrast to SDS, which is entirely digested in the small intestine at a slower rate than RDS, rapidly digestible starch is the starch portion that promptly increases blood glucose levels after consumption. The part of starch and/or starch hydrolysis products known as resistant starch enters the colon for fermentation after escaping digestion in the small intestine. Additionally, resistant starch has advantageous physiological effects that include enhancing intestinal health, raising mineral absorption, and reducing plasma triglyceride and cholesterol levels.

Interactions between starch and phenolic compounds

Effect of polyphenols on starch digestibility: The main dietary carbohydrate and energy source is starch. However, consuming more starchy foods has numerous negative effects, such as increasing the glycemic response, which can lead to obesity, diabetes, and other chronic disorders. Consequently, it has been advised to eat more low-glycemic meals. The use of phenolic compounds to decrease starch digestibility could be one method to lower the glycemic index of food products. Several enzymes are involved in the breakdown of starch, including intestinal α-glucosidases, pancreatic and salivary α-amylases, and others. It is crucial to take into account how phenolics affect each enzyme as a result.

High Glycaemic Index (GI) foods are those high in carbohydrates or starches that raise blood sugar quickly, while low GI foods raise blood sugar gradually). Low GI (GI 6 55), medium GI (GI 56 6 GI 6 69), or high GI are possible categories (GI 70). It is well recognized that diet is important for the etiology and treatment of obesity and diabetes.

Quantitatively, the most significant dietary energy source for humans is carbohydrates, which typically make up between 47% and 70% of total energy intake. They are crucial for both glucose homeostasis and energy metabolism.

The world health organization estimates that 9% of adults worldwide have diabetes, and Type 2 Diabetes (T2D) is anticipated to have an unusual rise in prevalence. Postprandial hyperglycemia, a risk factor for T2D and endothelial dysfunction, may result from routine exposure to meals with a high glycemic load (a measure of the overall blood glucose raising effect of a serving of food) components of polyphenols McDougall GJ, et al., may aid in delaying the digestion of starches and disaccharides as well as the absorption of glucose after consuming a carbohydrate rich meal or beverage.

When individual phenolic acids were added to a cooked starch slurry, the amount of starch hydrolysis with a-amylase and amyloglucosidase decreased by up to 8%; the declines were more evident when phenolic acids were supplied in bulk.

Numerous studies, including randomized controlled trials and observational prospective cohort studies, demonstrate a beneficial relationship between low GI food consumption and the prevention of obesity, diabetes, and cardiovascular illnesses. The number of carbs consumed also affects the glycaemic response. The Glycaemic Load (GL), which accounts for the number of carbs in a meal, is a measurement used to determine the overall glycaemic effect of a portion of food. The Glycemic Index (GI) is a scale that was developed to allow comparisons between foods high in carbohydrates and their glycemic reaction. Foods are ranked according to their GI according to how their postprandial blood sugar response compares to a reference food. The rate of digestion or absorption of carbohydrates in food is the key factor that affects GI. According to Bjorck, Lilberg, and Osterman, the rate and extent of starch digestion trigger several physiological processes that have a variety of positive effects on health. These include reduced glycaemic and insulinemic responses to food, hypocholesterolemic effects, and protection against colorectal cancer. Increased intake of low Glycaemic Index (GI) foods was advised in a recent joint FAO/WHO expert review. A low glycemic index diet may benefit diabetic patients as well as healthy individuals by improving metabolic control of hyperlipidemia, according to a growing body of research [20].

To help people choose the best carbohydrate containing foods for the maintenance of health and treatment of various diseases, the FAO/WHO Expert Consultation recommended the adoption of the GI concept for classifying carbohydrate rich foods. Low GI foods have a lower incidence and prevalence of diabetes, heart disease, and various malignancies because the slow digestion and absorption of their carbs result in a more gradual rise in blood glucose and insulin levels. Food products containing resistant starch have lower GI values and can therefore be used for applications requiring controlled glucose release.

Despite various strategies being used to control it, type 2 diabetes is becoming more common, especially in Low and Middle Income Countries (LMIC), where it is most prevalent. Additionally, the number of fatalities caused by its complications is rising. As a result, it has become a significant public health issue, particularly for those who live in these areas.

Consuming foods with recognized nutraceutical characteristics may assist to regulate diabetes, which is heavily influenced by diet. The inhibition of starch digestion enzymes like α-amylase and α-glucosidase that are involved in the breakdown of starch is one of the main objectives in the therapy of type 2 diabetes mellitus. Starch nutritional makeup (Rapidly Digested Starch (RDS), Slowly Digestible Starch (SDS), and Resistant Starch (RS), food processing methods, dietary fiber, and others) have all been demonstrated to have an impact on how easily starches are absorbed by humans. These elements frequently affect the increase in blood sugar that occurs after eating.

Postprandial hyperglycemia, hyperinsulinemia, and other metabolic abnormalities are brought on by foods high in readily available carbs, such as starch or sugar. Consistent intake of high glycemic meals may consequently raise the risk for obesity, type 2 diabetes, and cardiovascular disease because the quick absorption of glucose defies the control systems of glucose homeostasis. The obvious goals for improved glycemia management following high carbohydrate meals are carbohydrate digestion and glucose absorption. The principal enzymes in the conversion of dietary carbohydrates to glucose are α-amylase and α-glucosidase. Through the use of certain transporters, the freed glucose is absorbed by the intestine enterocytes. By slowing down the rate of glucose release and absorption in the small intestine, inhibition of the digestive enzymes or glucose transporters might prevent postprandial hyperglycemia.

When cooked with normal and high amylose maize starch, a tannin sorghum extract was much more effective at reducing starch digestibility, according to Lemlioglu-Austin, et al., report. This resulted in a lower Estimated Glycemic Index (EGI) and higher Resistant Starch (RS) (15-58%) compared to non-tannin treatments.

According to Hargrove, et al., black sorghum phenolic extracts (without tannins) or tannins both inhibit a-amylase and the inhibitory activity increases with phenolic extract content. It has been demonstrated that employing phenolics from plant extracts to fortify bread is an efficient technique to slow down the rate of bread digestion. According to a paper, green tea phenolics interact with amylose through hydrogen bonding, lowering the starch's digestibility. Similar to this, Swieca, et al., found that 5% quinoa leaves reduced the starch digestibility of bread by 11.8% compared to control bread. Studies by Liu, Wang, Peng and Zhang, Koh, Wong, Loo, Kasapis and Huang, Yilmazer-Musa, Griffith, Michels, Schneider and Frei, revealed that tea polyphenols, such as tea catechins, inhibited the activity of α-amylase and α-glucosidase, two essential enzymes for starch digestion in human. Another study found that tea polyphenols were the most effective at inhibiting the activity of the a-amylase among the 4 types of digestive enzymes (pepsin, trypsin and lipase) examined. Adsorbed polyphenols on granular starch may also have an inhibiting effect on α-amylase. By attaching to the enzyme's active sites and generating competitive inhibition or by attaching to the enzyme substrate complex and causing mixed type inhibition, tea polyphenols can reduce the activity of -amylase. Many phytochemicals, including green coffee extracts, tea extracts, and pomegranate extracts, have been investigated for their inhibitory effect against α-amylase.

McDougall, et al., examined the inhibitory efficacy of various soft fruit extracts against α-glucosidase and found that the anthocyanins rich fraction successfully inhibited the enzyme. According to Matsui, et al., anthocyanins from different plants may have the ability to block α-amylase and prevent the rise in postprandial glucose levels caused by starch.

According to Thompson, Yoon, Deshpande and Salunke, Tamir and Alumot and Yoon, et al., polyphenols and phytic acid may interact with the amylase enzyme, with proteins that are closely associated with starch, or directly with the starch to affect how easily it can be digested. Additionally, the action of phytic acid, which is known to catalyze amylase activity, may result from its interaction with calcium.

Complex polysaccharides are broken down by alpha amylase into oligo and disaccharides, which are then hydrolyzed by glucosidases into monosaccharides and absorbed in the small intestine, raising postprandial glucose levels. Functional foods have gained popularity recently due to their functions in treating a variety of metabolic illnesses, including type 2 diabetes Eleazu, et al. One of the earliest visible impairments in glucose homeostasis linked to type 2 diabetes mellitus is postprandial hyperglycemia. Postprandial hyperglycemia is substantially influenced by the monosaccharides absorbed and the speed of absorption in the small intestine, and it is mediated by enzymes that break down carbohydrates, such as pancreatic alpha amylase and intestinal α-glucosidase.

An important strategy in the control of postprandial blood glucose levels in type 2 diabetic patients and borderline patients is the inhibition of these enzymes, which can considerably lower the levels of blood glucose after a mixed carbohydrate diet.

Effect of phenolic compounds on pasting properties of starches

Amylose, lipid and branch chain length distribution of amylopectin all have an impact on the starch's pasting qualities. Amylopectin causes starch granules and pastes to enlarge, but amylose and lipids prevent this from happening. Among the crucial functional traits of starch are its pasting abilities. Increased viscosity (pasting) results from amylose leaching out into the aqueous phase when an aqueous suspension of starch is heated above a certain temperature. The granules become extremely vulnerable to heat and mechanical breakage as a result. Peak viscosity is the point at which heated gelatinized starch reaches its highest level of viscosity. It shows how well a starch can bind water. The variation in peak sharpness was remarkable. Because there was less molecular bonding, this differed among different fractions. Because of the almost uniform and spontaneous swelling compared to smaller granule fractions, this helps starches reach sharper peaks.

RVA measurements of the pasting qualities are frequently used as important predictors of how starch would behave throughout processing. In the RVA test, starch and water are combined to facilitate hydration and are held briefly above ambient temperature. Granules of starch swell as a result of heating. An increase in viscosity, which represents the pasting process, may be seen as the temperature rises more. Peak Viscosity (PV), which often indicates the capacity of starch to bind water and is correlated with the quality of the final product, is reached when the rate of granules swelling equals the rate of granules collapsing. The temperature at the commencement of viscosity rises with further heating. Higher peak viscosities in corn and potato starches make them more effective thickening agents in food systems. According to Karim, et al., granule integrity and stiffness may have decreased as a result of the decline in PV. Once peak viscosity is reached, granule disintegration causes a drop in viscosity. Breakdown viscosity is the difference between peak and trough viscosity and measures the degree of granule disintegration. Typically, breakdown viscosity indicates the level of stability during cooking.

Starch retrogradation causes the viscosity to rise once again once cooling gets underway. Leached amylose and long linear amylopectin depolymerization (degradation) of these molecules are substantially to blame for the setback and final viscosities. Setback, which is connected to syneresis or weeping during freeze-thaw cycles, is a textural indicator for the finished product.

Studies have looked into the interactions between phenolic compounds and starch, specifically how different phenolic compounds affect the starch's ability to paste. Peak viscosity was markedly raised when phytochemical extracts from pomegranate, green tea, and Chinese galls were added to wheat starch. 21 out of the 25 pure phenolic compounds tested for their impact on wheat starch's ability to paste were found to improve peak viscosity. Peak viscosity was likewise raised by each of the 12 phenolic acids investigated.

According to Beta and Corke, inclusion complexes can explain how tiny phenolic compounds like ferulic acid and catechin interact with starch (clathrates). These phenolic chemicals create inclusion complexes with amylose molecules like how lipids do, which reduces the ability of maize and sorghum starches to expand. Additionally, hot paste and final viscosities were lowered by ferulic acid and catechin. The development of starch-phenol complexes that prevented the reassociation of starch molecules was thought to be the cause of these decreases. Although catechin was found to bind with amylose, ferulic acid had a greater impact on the pasting properties.

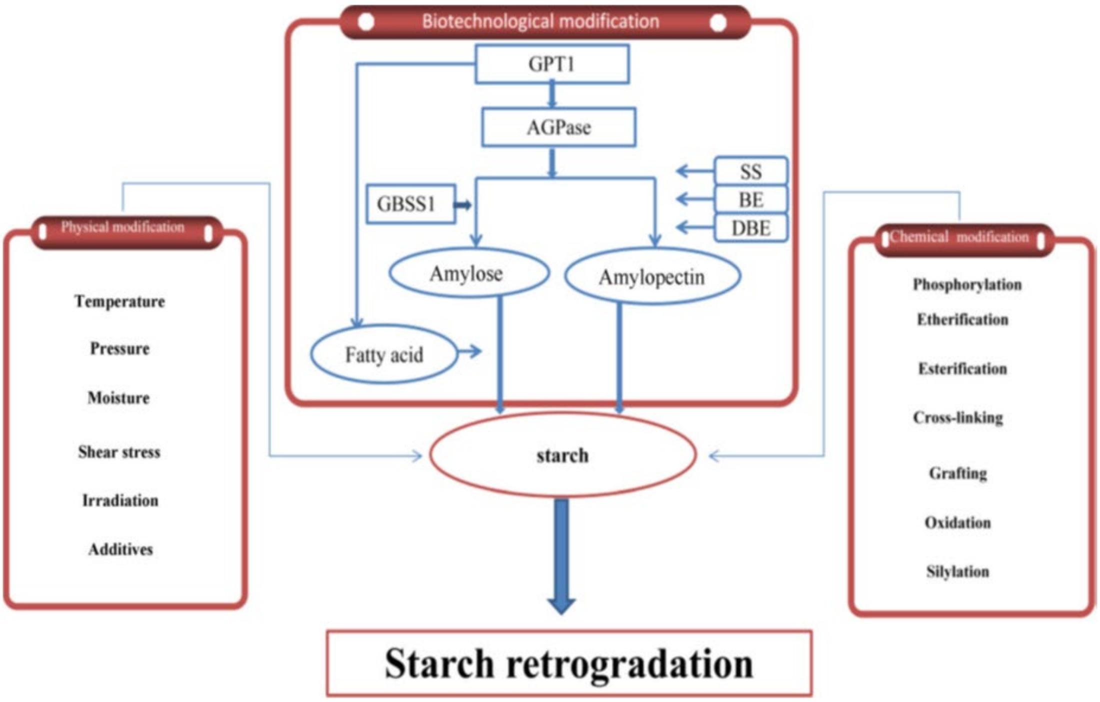
Effect of polyphenols on starch retrogradation

Retrogradation, which implies entirely reversible recrystallization in the case of amylopectin and partially irreversible recrystallization in the case of amylose, refers to the changes that take place in gelatinized starch following chilling. With retrogradation, the starch gel becomes noticeably more hard or firm. The disordered chains undergo re association through hydrophobic contacts and hydrogen bonding as the gelatinized starch cools. Retrogradation is the name for this action. Black tea extract raised the gelatinization temperatures and DH of rice, corn, and soybean starches, but had minimal impact on potato starch. The gelatinization temperatures (To, Tp, and Tc) and DH of rice starches increased by 2-4°C and 1 J/g, respectively, as the content of black tea extract was increased from 5 to 15%. Through hydrogen bonding, the hydroxyl and carboxyl groups of the solubilized phenolic compounds may interact directly with water and indirectly with the hydroxyl groups of starch, changing the characteristics of both the water and the starch. Retrogradation of starch typically results in a decline in product quality, Starch retrogradation has been controlled by a variety of approaches, which can be neatly divided into three categories: biotechnological alterations, chemical modifications, and physical modifications (Figure 2). The main method of biotechnological modification is genetic modification, which alters the structure of starch to affect retrogradation by regulating the expression of enzymes involved in starch production. Starch's molecular structure is altered *via* chemical changes that introduce functional groups to affect retrogradation. Cross linking, esterification, and oxidation are a few examples of chemical changes. Changes in temperature, pressure, humidity, shear stress and storage conditions have all been physically made to regulate or hinder starch retrogradation. Another crucial component of physical alterations is the addition of dietary components such as proteins, lipids, and nonstarch polysaccharides. In plant based foods including chocolate, popcorn, tea, soybeans, red wine, fruits, and vegetables, there are polyhydroxy chemicals known as polyphenols that may be beneficial to human health. There are a lot of free hydroxyls in polyphenols. During the gelatinization process, these free hydroxyls may establish hydrogen bonds with starch. Starch retrogradation might be slowed down by a hydrogen bond that forms between polyphenols and starch. Varying polyphenols hydroxyl content and reactivities have different effects on how long starch retrogradation is delayed. The inclusion of polyphenols during the production of starch or starchy foods could not only prevent starch retrogradation but also increase the nutritional content of the finished goods.

While amylopectin molecules re-crystallize by the interaction of their short chains, amylose molecules associate with other glucose units to create a double helix during retrogradation. Because of the weakening of its crystalline structure during retrogradation, starch displays lesser gelatinization and enthalpy than natural starch. Each polymer has a variable rate of recrystallization, and amylopectin and intermediate components affect the retrogradation process during storage under refrigeration. Starch is easily recrystallized below 0°C, but it can also happen over 100°C. Repeated freezing and thawing of paste accelerates starch retrogradation.

Purified green tea polyphenols may reduce the rate of starch retrogradation when added. After 10 days of storage, rice starch with 10%, 14%, or 20% tea polyphenols did not display retrogradation endotherm on the DSC. The authors hypothesized that tea polyphenols hydroxyl groups interact with starch molecules OH groups to prevent the reassociation of starch polymers during retrogradation. The strength of the hydrogen bonds between starch and the polyphenols may also have an impact on this outcome. Regardless matter how much amylose is in the rice starch, green tea polyphenols can slow down retrogradation. In actuality, it took 20 days of storage before the retrogradation enthalpy of starches containing 10% or 15% polyphenols could be measured. Additionally, the amount of retrogradation was significantly decreased. As an illustration, 15% of tea phenolics added to high amylose rice starch decreased retrogradation from 79% (control) to 11.7%. According to Barros, et al., the viscosity values rose as the content of phenolic extract rose. Similar results were seen for peak time, which varied between 8.3 and 8.8 minutes as opposed to 8.1 minutes for the control. The concentration of sorghum phenolic extracts increased, and the mixture of starch and phenolic extract contained more solids, which may have had an impact on the RVA parameters, according to the author's observations. The greatest quantity of phenols was found in the phenolic extracts of black and tannin sorghum (about 10 times more than the white sorghum phenolic extract). Therefore, changes in starch pasting properties observed after cooking freeze dried phenolic extracts from black and tannin sorghum could be attributable to either the presence of more phenols in a solution that compete with starch for water or potential interactions between black and tannin sorghum polyphenols and starch. As the concentration of black and white sorghum phenolic extract increased during cooling, the ultimate viscosity increased as well. Setback tended to grow as the concentration of tannin sorghum phenolic extract grew, while it tended to decrease when the concentration of white and black sorghum phenolic extract increased. This may assist slow down the retrogradation of starch by indicating some interaction between tannins and leached amylose. The evidence suggests that tannin sorghum's proanthocyanidins and white and black sorghum's low molecular weight polyphenols interact with starch in various ways. According to Zhu, the alterations may have resulted from hydrogen bonding as well as a potential change in the pH of the solution caused by the polyphenols.

Figure 2. Effects on starch retrogradation. The blue part of biotechnological modification was redrawn by Kharabian-Masouleh, et al, GPTI, glucose 6-phosphatase translocator; AGPase, ADP glucose pyrophosphorylase; SS, starch synthases; BE, branching enzymes; DBE, debranching enzymes.



Effect of polyphenols on the quality of baked products

Previous research has examined how to plant extract fortification affects the physical and sensory properties of bread. The amount of added ABREP had a positive relationship with the bread crumb's hardness and chewiness, and increases in hardness were shown to be statistically significant ($P \leq 0.05$). With increasing levels of additional ABREP, significant declines in springiness, cohesion, and resilience were seen. The bread supplemented with 4% ABREP and the control bread both had a considerable increase in hardness, from 284 to 457 N, respectively. This increase in hardness could be attributed to the weak gluten networks' poor capacity to retain gas, which leads to a compact structure in the breadcrumb. Wang R, et al., found that the hardness and stickiness increased as the number of green tea extracts increased.

DISCUSSION

The qualitative characteristics of bread fortified with quinoa leaves revealed an increase in bread crumb hardness and a decrease in bread volume with an increase in quinoa leaf percentage (up to 5%) in the wheat dough.

Similar effects of green tea powder on the textural characteristics of sponge cake were observed by Lu, et al. The reduction in cake volume with increasing green tea concentration was due to an increase in cellulose. Along with the rise in hardness came a decrease in volume. In addition, whereas gumminess and chewiness increased with green tea powder, cohesiveness, adhesiveness, springiness, and resilience decreased. Despite these modifications, sensory liking tests indicated that up to 20% of the flour could be replaced with green tea powder without being rejected. Green tea powder was added to sponge cakes in a recent study by Lu, et al., who then looked at the cakes' composition and antioxidant qualities. All replacement levels (10%, 20%, and 30%) considerably improved the overall dietary fiber intake. Fiber content increased from 0.65% (control) to 2.51% at a replacement level of 30% (GT30). Protein and ash levels were dramatically boosted by GT30. Due to the presence of various catechins, the addition of green tea powder significantly boosted the cakes antioxidant capabilities.

According to Sui et al., there was a significant difference between newly baked bread dough with ABREP and dough without it ($p>0.05$). The control bread, with a specific volume of 3.5 cm^3/g after baking, had the highest specific volume. The specific volume of baked bread gradually reduced as the amount of ABREP in the flour increased, reaching 2.89 cm^3/g for 4% ABREP, which was considerably (p 0.05) less than the control bread.

The addition of phenolic acids decreased bread volumes, and bread enriched with caffeic acid had a considerably lower volume (2.39 cm^3/g) than control bread (2.79 cm^3/g), according to Han and Koh's research. The production of bread largely depends on oxidizing and reducing (redox) agents, such as sodium metabisulfite and L-cysteine as reducing agents and ascorbic acid and azodicarbonamide as oxidizing agents.

CONCLUSION

This review summarized effects of dietary compounds including cell walls, proteins, lipids, non-starchy polysaccharides, and polyphenols on starch enzymatic digestion and their underlying mechanisms were discussed. Dietary compounds lowered starch digestion through three pathways:

- Retained starch ordered structures or formed ordered assemblies chaperoned with these dietary compounds.
- Formed physical barriers and prevented enzymes from accessing/binding to starch.
- Reduced enzymes activities.

Cell walls, proteins, and non-starchy polysaccharides restricted starch disruption during hydrothermal treatment and the retained ordered structures limited enzymatic binding. In addition, they encapsulated starch granules and formed physical barriers for enzymes accessing. Proteins, non-starchy polysaccharides along with lipids and polyphenols interacted with starch and formed ordered assemblies. Non-starchy polysaccharides and polyphenols showed robust ability to reduce activities of α-amylase and α-glucosidase. Comparing with cell walls, protein, and non-starchy polysaccharides, lipids and polyphenols had stronger ability to slow starch digestion.

Author statement

Haamid Mujtaba: Investigation and writing the original draft. Banwar Lal Jatt: Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

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