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MINI-REVIEW

Effect of resistant starch types as a prebiotic

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Abstract

Since the role of intestinal microbiota in metabolism was understood, the importance of dietary components such as fibres and prebiotics, which affect the modulation of microbiota, has been increasing day by day. While all prebiotic components are considered dietary fibre, not every dietary fibre is considered a prebiotic. While fructooligosaccharides, galactooligosaccharides, inulin, and galactans are considered prebiotics, other fermentable carbohydrates are considered candidate prebiotic components based on in vitro and preclinical studies. Resistant starch, one of such carbohydrates, is considered a potential prebiotic component when it is made resistant to digestion naturally or chemically. In this review, both in vitro and in vivo studies in which the prebiotic capacity of type II, type III, and type IV resistant starch isolated from food and produced commercially was assessed were analyzed. According to the results of current studies, certain types of resistant starch are thought to have a high prebiotic capacity, and they may be candidate prebiotic components although positive results have not been achieved in all studies.

Key points

- *Resistant starch is undigested in the small intestine and is fermented in the large intestine.*
- *Resistant starch fermentation positively affects the growth of Bifidobacterium and Lactobacillus.*
- *Resistant starch can be considered a prebiotic ingredient.*

Keywords Resistant starch · Prebiotic · Microbiota · Fibre

Introduction

Microorganisms in the intestinal microbiota which function as a regulator play various roles in metabolic, physiological, and immunological processes. Physiological or environmental factors such as genetics, age, illness, stress, and medication use affect the gut microbiota (Ashaolu et al. 2021). Due to its role in the etiology of various diseases, studies in which the relationship between nutrition and microbiota is investigated have gained momentum with the increasing interest in food and dietary components that affect the composition and modulation of the intestinal microbiota (Martinez et al. 2015). With the understanding of the importance of intestinal microbiota on human health and the use of probiotics to modulate the microbiota, studies in the field of probiotics have increased a great deal. The International Scientific Association for Probiotics and Prebiotics (ISAPP) defined probiotics as "live microorganisms that, when administered in adequate amounts, confer a health benefit on the host" (Hill et al. 2014). The effective use of probiotics has been reported in the treatment of gastrointestinal diseases in many studies (Gungor et al. 2013; Trush et al. 2020). Lactic acid bacteria (LAB) constitute a significant proportion of probiotic cultures, and they are naturally found in many foods. LAB species have a particular interest in food industries due to their technological properties (Dincer and Kıvanc 2012, 2020). Environmental factors help mediate the composition and metabolic functions of the gut microbiota and consumption of certain dietary components, especially fibres and prebiotics, and can modulate the gut microbiota. Dietary fibres and prebiotics are fermented by bacteria in the intestine, and they affect the composition and metabolic activities of the intestinal microbiota (Ashaolu et al. 2021).

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Among the components of dietary fibre are non-starch polysaccharides (cellulose, hemicellulose, pectin, inulin, and fructans), non-digestible oligosaccharides (fructooligosaccharides, galactooligosaccharides), lignin, a phenylpropane polymer, and resistant starch. In other words, dietary fibre is defined as carbohydrates and lignin which are found in plants, not digested in the small intestine, but partially or completely fermented in the large intestine (Włodarczyk and Śliżewska 2021). There is a consensus on the health effects of dietary fibre, although it is defined in several ways in the literature. The incidence of non-communicable chronic diseases is lower in populations consuming dietary fibre in high amounts than in populations consuming dietary fibre in low amounts. Among the effects of dietary fibre on health are the modulation of intestinal microbiota, decrease in blood glucose and cholesterol levels, increased satiety, and decrease in the risk of developing some types of cancer and cardiovascular diseases (Carlson et al. 2018). In addition to these effects of dietary fibres on health, it is known to affect the composition and metabolic activity of some intestinal bacterial communities by increasing the production of short-chain fatty acids (SCFA). Therefore, some fibres can be classified as prebiotics (Rezende et al. 2021).

The concept of prebiotic was first introduced in the 1990s, and in 1995, it was defined by Gibson and Roberfroid as "an indigestible food component that beneficially affects the host and improves the health of the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon" (Gibson and Roberfroid, 1995). Today, prebiotics are considered selectively fermentable components that cause specific changes in the composition and/or activity of the gastrointestinal microbiota and benefit the health of the host. This definition suggests that the effects of prebiotics are not limited to the colon but can occur in any part of the gastrointestinal tract. The prebiotics having been identified so far are classified as dietary fibre. However, not every dietary fibre is considered a prebiotic. In this context, for a compound to be classified as a prebiotic, it must meet certain criteria. For a food component to be considered prebiotic, it should be resistant to stomach acid, hydrolysis by mammalian enzymes, and gastrointestinal absorption; it should be fermented by the intestinal microbiota; and it should selectively stimulate the growth and/or activity of healthy intestinal bacteria (Gibson et al. 2010). Prebiotics should not lead to adverse effects such as the growth of pathogenic microorganisms or distension caused by excessive gas production. Studies show that prebiotics primarily support an elective increase in probiotics (Włodarczyk and Śliżewska 2021; Rezende et al. 2021). The majority of the microorganism comes from lactic acid bacteria, and strains that are used as probiotics usually are members of *Lactobacilli* and *Bifidobacteria* (Dincer and Kıvanc 2021). In addition to supporting *Lactobacillus* and *Bifidobacterium* populations, prebiotics are known to promote the growth of beneficial bacteria such as *Akkermansia*, *Eubacterium*, *Propionibacterium*, *Faecalibacterium*, and *Roseburia* (Włodarczyk and Śliżewska 2021; Rezende et al. 2021).

According to data in the literature, fructooligosaccharides, galactooligosaccharides, inulin, and galactans are considered prebiotics. Based on in vitro and preclinical studies, other fermentable carbohydrates can be considered candidate prebiotic components (Rezende et al. 2021). It has been shown that resistant starch, one such carbohydrate, is fermented by the intestinal microbiota and that it promotes SCFA production. In the literature, there is also evidence that resistant starch can modulate the growth of gut bacteria involved in butyrate production in humans (James et al. 2015). There are different types of resistant starch based on their chemical structure and properties. Some resistant starch types that have become resistant to digestion naturally or chemically have the potential to have the prebiotic capacity (Rezende et al. 2021). Especially in the last few years, there has been a significant increase in the number of studies conducted on this issue. However, the prebiotic capacity of resistant starch has not been evaluated in detail within the scope of in vitro and in vivo studies. In this review, current studies investigating the prebiotic capacities of resistant starch types isolated from food or produced commercially are evaluated together for the first time. Also, the capacity of different probiotic/potential probiotic bacteria to use resistant starch types was analyzed at the species level. In addition, in vitro and in vivo methods used for determining the prebiotic capacity of resistant starch are explained in detail. Consequently, based on the studies in the literature, the prebiotic capacities of different resistant starch types have been discussed all in aspects.

What is resistant starch?

Starch, a polymeric carbohydrate produced by plants for energy storage, is one of the main forms of dietary carbohydrates (Snelson et al. 2019). Starch consists of amylose, which has a linear α1-4 bond structure and typically constitutes 15–20% of starch, and amylopectin, a larger branched molecule with α1-4 and α1-6 bonds. Two basic crystalline starch structures have been defined as A and B types containing amylopectin at different proportions. While type A starches are found in grains, type B starches are found in tubers and foods rich in amylose. There is also a third type, called "type C", which is found in legumes as a mixture of both A and B forms (Snelson et al. 2019; Dupuis et al. 2014). According to its nutritional properties, starch is divided into three main classes: rapidly digestible starch, slowly digestible starch, and resistant starch. While rapidly digestible starch is hydrolyzed to dextrins by α-amylase

enzyme within 20 min after consumption, slowly digestible starch is hydrolyzed within 20–120 min after consumption. Resistant starch is not hydrolyzed after 120 min in the small intestine of healthy individuals but can be fermented in the large intestine (Dupuis et al. 2014). Information on the types and some properties of starch according to the digestion status is given in Table 1 (Ashwar et al., 2016).

Resistant starch is defined as the starch fraction that is resistant to digestion by α-amylase and pullulanase enzymes in vitro and can be fermented in the colon. In 1982, Englyst et al. discovered resistant starch for the first time by discovering that some starch remained in the medium after enzymatic hydrolysis of non-starch polysaccharides in an in vitro environment (Englyst et al. 1982). In subsequent studies conducted with healthy ileostomy subjects, it has been shown that starch resistant to digestion exists in the stomach and small intestine and that it may be fermented in the large intestine (Englyst et al. 1996). As a result, resistant starch has been accepted as the sum of starch and the degradation products of starch that are not digested in the small intestine of a healthy person (Włodarczyk and Śliżewska 2021). The amount of resistant starch can be measured as the difference between the total starch and the sum of rapidly digestible starch and slowly digestible starch. The resistance of resistant starch to digestion varies according to the ratio of amylose to amylopectin in its structure. While amylose is digested slowly, amylopectin is digested rapidly. Therefore, an increase in the amylose content of resistant starch is associated with a slower digestibility rate (Ashwar et al. 2016).

Types of resistant starch

There are five types of resistant starch according to their chemical structure called type 1–2-3–4-5 (Włodarczyk and Śliżewska 2021).

Type I resistant starch is starch molecules inside plant cells whose walls have not been damaged. Since the enzymes in the gastrointestinal system cannot break down cellulose, hemicellulose, and lignin, common components of plant cell walls, amylolytic enzymes cannot reach this starch. Therefore, type I resistant starch passes into the large intestine without being digested in the small intestine (Włodarczyk and Śliżewska 2021). Grinding and chewing can make type I resistant starch more accessible and less resistant to digestion. Type I resistant starch is heat stable in most normal cooking processes (Fuentes-Zaragoza et al. 2011). Cereals, seeds, legumes, and pasta are considered nutritional sources of type I resistant starch (Włodarczyk and Śliżewska 2021; Ashwar et al. 2016; Lockyer and Nugent 2017; Jiang et al. 2020).

Type II resistant starch is natural starch granules resistant to digestion due to the structure of the starch granule. These non-gelatinized starches are resistant to digestion due to their compact structure. High amylose corn starch, which is among the Type II resistant starch varieties, remains stable by preserving its structure and resistance during the processing and preparation of many foods (Ashwar et al. 2016; Fuentes-Zaragoza et al. 2011) and can be added to foods to increase total dietary fibre intake without changing the physicochemical properties of foods (Maziarz et al. 2013). High amylose corn starch, raw potato starch, and raw banana starch are considered nutritional sources of type II resistant starch (Włodarczyk and Śliżewska 2021; Ashwar et al. 2016; Lockyer and Nugent 2017; Jiang et al. 2020).

Type III resistant starch is formed by cooling starchy foods after cooking. It contains retrograde starch or crystalline non-granular starch (Ashwar et al. 2016; Fuentes-Zaragoza et al. 2011). It is produced from natural starch in a three-step process. In the first step, called gelatinization, the granular structure is degraded by heating in excess water. In the second step, called retrogradation, recrystallization of amylose molecules takes place upon cooling or dehydration of the starch solution. In the final step, the resistant fraction is isolated through partial enzymatic digestion of the amorphous phase (Fuentes-Zaragoza et al. 2011; Maziarz et al. 2013). Cooked and then cooled foods (potatoes, pasta, rice) and starch products with special heat treatment (bread, cakes, cereals) are considered nutritional sources of type III resistant starch (Włodarczyk and Śliżewska 2021; Ashwar et al. 2016; Lockyer and Nugent 2017; Jiang et al. 2020).

Table 1 Types and properties of starch

Types of starch			
	Rapidly digestible starch	Slowly digestible starch	Resistant starch
Digestion time (min)	20	20–120	> 120
Digestion (region of gastrointestinal system)	Mouth and small intestine	Small intestine	Large intestine
Nutritional sources	Freshly cooked food	Corn starch, millet, legumes	Raw bananas and potatoes
Physiological feature	Fast energy source	Slow-continuous energy source	Prebiotic
Structure	Amorphous	Amorphous/crystal	Depending on type

Type IV resistant starch is chemically modified starch produced by cross-linking, etherification, or esterification (Fuentes-Zaragoza et al. 2011). It is produced by cross-linking starches from rice, wheat, corn, potato, tapioca, oat, and mung beans using sodium trimetaphosphate, sodium tripolyphosphate, epichlorohydrin, or phosphoryl chloride (Du et al. 2020). The resistance of type IV resistant starch varieties to digestion increases depending on their substitution with different functional groups (Włodarczyk and Śliżewska 2021).

Type V resistant starch is a complex structure formed by the combination of amylose and lipids resistant to enzymatic digestion. Since the amylose–lipid complex has a complex structure, it resists digestion by amylase. In addition, the amylose–lipid complex limits hydrolysis against the enzyme amylase by preventing the swelling of starch granules (Okumus et al. 2018).

Food sources and commercial forms of resistant starch

Although resistant starch is found in all starchy foods, its amount may vary depending on the methods used during processing or storage (Fuentes-Zaragoza et al. 2011). Size and type of starch granules, physical form of grains and seeds, plant genotype and mutations, relationships between starch and other food components (lipids, proteins, sugars, gums, other fibre types and plant bio-actives which inhibit α-amylase), and food processing methods such as grinding, cooking, high-pressure processing, autoclaving, extrusion, and storage time affect the resistant starch content of foods (Lockyer and Nugent 2017). Whole grains, seeds, legumes, and other starch-containing foods are among the rich sources of resistant starch. Among the unprocessed foods, unripe bananas whose resistant starch ratio ranges between 47 and 57% are the richest source of resistant starch. Starches of tuberous vegetables such as potatoes contain resistant starch with type B crystallinity, which is highly resistant to enzymatic digestion. On the other hand, Legume starches whose resistant starch rate is 24.7% are another rich source of resistant starch with type C crystallinity (Ashwar et al. 2016; Tekin and Fisunoglu 2020). In Table 2, the amounts of resistant starch in commonly consumed foods are given. Resistant starch amounts in the foods in Table 3 were calculated based on the dry weight (Patterson et al. 2020).

In addition to resistant starch obtained from natural foods, there are also resistant starch types produced in commercial form from foods such as corn, tapioca, wheat, and potatoes (Ashwar et al. 2016; Ingredion 2022). Generally, commercially produced resistant starches are type II, type III, and type IV resistant starches (Ingredion 2022).

Table 2 Resistant starch amount of some commonly consumed starchy foods*

Foods	Resistant starch amount (g/100 g)** Mean (min–max)
Cereals and cereal products	
Buckwheat (groats and cooked)	1.8 (1.1–2.6)
Bread (white)	1.2 (0.1–4.4)
Bread (whole wheat)	1.0 (0.5–1.5)
Oats (uncooked)	11.3 (7.8–14.8)
Barley (grained and cooked)	2.4 (1.1–4.2)
Millet (cooked)	1.7
Rice (brown and cooked)	1.7 (0– 3.7)
Rice (white and cooked)	1.2 (0–3.7)
Pasta (cooked)	1.1 (0.5–1.5)
Pasta (whole grain)	1.7 (0–3.7)
Breakfast Cereals	
Cornflakes	3.2 (1.8–6.3)
Granola	0.1
Muesli	3.3 (2.3–4.3)
Vegetables	
Pea (cooked)	1.9 (0.9–2.2)
Potatoes (boiled)	1.3 (0.3–4.5)
Potatoes (cooked)	1.0 (0.8–1.4)
Sweet potatoes (baked)	0.7 (0.3–1.1)
Fried potatoes	2.8 (1.3–5.5)
Corn (cooked)	0.3
Yams	1.5
Banana (raw)	4.0 (0.3–6.2)
Banana (plantain/cooked)	3.5
Legumes	
Beans (white, canned/cooked)	4.2 (1.8–8.3)
Mung beans (canned/cooked)	1.6 (1.3–1.8)
Chickpeas (canned/cooked)	2.6 (0.8–4.3)
Lentil	3.4 (1.6–9.1)

*Patterson et al. 2020

**Resistant starch amounts of foods were calculated on the dry weight

Commercially produced resistant starch types are used as a food ingredient in various products. Commercially produced resistant starch types are not affected by processing or storage conditions; therefore, they are more advantageous than natural resistant starch sources. These products, which are used as food components in various products, are used to increase the total dietary fibre content of foods without affecting the taste or texture of the food (Ashwar et al. 2016; Tekin and Fisunoglu 2020). Some characteristics of commercially produced resistant starch types are given in Table 4 (Ingredion 2022; MGP Ingredients 2022; Raigond et al. 2015).

Table 3 Commercial resistant starch types and properties

Commercial name of resistant starch	Source of resistant starch	Resistant starch type	Resistant starch percentage (%)
HYLON VII	High amylose corn starch	Type II	48.0
Hi-maize 1043	High amylose corn starch	Type II	50.0
Hi-maize 958	High amylose corn starch	Type II	22
S4180	High amylose corn starch	Type II	23
Hi-maize 260	High amylose corn starch	Type II	53.0
NOVELOSE 240	High amylose corn starch	Type II	53.0
NOVELOSE 260	High amylose corn starch	Type II	60.0
NOVELOSE 300	Retrogradation of high amylose corn starch	Type III	< 30.0
NOVELOSE 330	Corn	Type III	47.0
NOVELOSE 3490	Tapioca	Type IV	80.0
CrystaLean	Retrograde Maltodextrin (from high amylose corn starch)	Type III	19.2–41.0
C*Actistar	Retrograde Tapioca Maltodextrins	Type III	53.0
Neo-Amylose	-	Type III	87.0–95.0
FİBERSYM™ HA	High amylose corn starch	Type IV	> 70.0 (TDF)
FİBERSYM™ 80ST	Potato	Type IV	80.0 (TDF)
FİBERSYM® RW	Wheat	Type IV	90.0 (TDF)
Versafibe™1490	Potato	Type IV	74.2
Versafibe™2470	Corn	Type IV	65.0
Versafibe™2480	Modified Corn	Type IV	71.0

*TDF, total dietary fiber

Prebiotic capacity of resistant starch

Why is resistant starch considered a prebiotic?

Among the dietary fibre, polysaccharides and oligosaccharides, only hydrolytic enzymes digest starch and its breakdown products in the gastrointestinal tract. All non-starch polysaccharides and oligosaccharides pass into the large intestine without being digested in the small intestine and are fermented in the large intestine. Substrates essential for fermentation are other non-starch polysaccharides, and they exist in very small amounts in the stool. However, when other non-starch polysaccharides are not sufficient to meet the substrate needs of the microbiota, resistant starch may contribute to the fermentation in the large intestine (Kadyan et al. 2022). The results obtained from several studies indicate that over time, the SCFA profile increases in the large intestine and faeces samples after consumption of foods with high resistant starch content (Bojarczuk et al. 2022). Within this context, it is thought that resistant starch is the largest component that meets the substrate requirement of the microbiota and contributes to SCFA production and that it may potentially have a prebiotic capacity (Tekin and Fisunoglu 2020; Kadyan et al. 2022; Bojarczuk et al. 2022). Figure 1 shows the fermentation of resistant starch as a prebiotic by the microbiota and its prebiotic effects.

How is the prebiotic capacity of resistant starch determined?

Analysis of the existing literature reveals that it is possible to access various studies in which the prebiotic capacity of resistant starch is assessed. In some of these studies, the resistance of resistant starch to gastric acid, hydrolysis by mammalian enzymes, and gastrointestinal absorption have been investigated. In various in vitro applications, it has been observed that resistant starch is exposed to gastrointestinal acids and enzymes. In in vivo applications, it is possible to measure the substrate recovery from the stool by administering resistant starch orally and to determine the undigested resistant starch molecules in the distal ileum in various experimental animals such as rats. Based on the analysis of studies in general, it is possible to say that resistant starch shows resistance to digestive enzymes. In addition, literature data indicate that type II resistant starch naturally found in foods is naturally resistant to enzymatic digestion and that type III and type IV resistant starch can also be resistant to digestion through chemical modification ((Nayak et al. 2014; Zaman and Sarbini 2016). The fermentability of resistant starch by the gut microbiota has been investigated in various studies. While fermentability was investigated by carbohydrate fermentation tests in in vitro studies, in in vivo studies, SCFA profiles in faeces were determined, the presence of

Table 4 Prebiotic capacities of resistant starches isolated from various foods

Food source	Type of the experiment	Method	Results	References
Potatoes	In vitro	Isolated resistant starch nanoparticles were added to the MRS medium without carbon source (0.5% and 2%) and the proliferation of *Lactiplantibacillus plantarum* subsp. strain was observed for 96 h. Then, in the samples taken from the fermentation medium, lactic acid and SCFA were determined through high performance liquid chromatography (HPLC) analysis. Glucose containing MRS broth was used as a positive control in the study	At the end of the study, the viability was higher in the group to which 0.5% resistant starch particles were added (9.5 log CFU/mL) than was that in the control group (6.75 log CFU/mL) at the 70th h of fermentation. In addition, the butyric acid concentration continued to increase at the 96th h in the bacteria group to which 0.5% resistant starch particles were added, and it was 2.5 times higher than was that in the group whose carbon sourcewas glucose	(Wang et al. 2022a, b)
Indian Potatoes	In vitro	In this study, *Brevibacillus aydinogluensis* BTM9, *Lactobacillus gastrikus* BTM7, *Lactobacillus paracasei* CD4, *Lactobacillus fermentum* K75 and *Lactobacillus rhamnosus* GG strains isolated from various foods were used. The resistant starch isolated for the study was added to 11% skimmed milk (1 mg/ml and 25 mg/ml) and the proliferation of each probiotic strain was investigated	Among the probiotic strains tested, the prebiotic effect of resistant starch was observed in *L. paracasei* CD4 bacteria in the medium containing 1 mg/mL resistant starch compared to other probiotic cultures. It was determined that higher concentration of resistant starch did not have a significant proliferative effect on cultures	(Chakravarty et al. 2021)
Himalayan rice	In vitro	In this study, different strains of *Lactobacilli* such as *L. casei, L. brevis* and *L. plantrum* (1 ml each, 9–10 log CFU) were used. In the study, proliferation and SCFA production of each strain were investigated in the MRS broth medium containing 5% resistant starch solution instead of glucose	*Lactobacillus* fermentation of the resistant starch resulted in the production of acetic acid, butyric acid and propionic acid. In all the samples, the main product of fermentation was acetic acid. The results of the study demonstrated that resistant starch was used by *Lactobacillus* in SCFA production	(Ashwar et al. 2021)
Semen coicis	In vitro	Four different type III resistant starches obtained by different methods and commercially available high amylose cornstarch were added to the fermentation medium as carbon source and the proliferation of *Bifidobacteria adolescentis* strain was investigated in each prepared medium. Then, SCFAwas determined in the samples taken from the fermentation medium through gas chromatography (GC) analysis	At the end of the study, the researchers reported that the *B. adolescentis* strain used all resistant starch types as a carbon source, and they observed the highest growth in the medium containing the *S.coicis* resistant starch variety purified through microwave moisture treatment. When SCFA produced after fermentation was examined, it was determined that the production of acetic, propionic and butyric acids was higher in type III resistant starch varieties	(Bao et al. 2017)
Peas	In vitro	In this study, resistant starches obtained from natural and retrograde autoclaved peas were fermented for 24 h with fecal samples collected from 4 healthy individuals, and the microbiota composition, and the amount of SCFA were checked through GC analysis	Post-fermentation acetate, propionate and butyrate levels of pea starches increased gradually throughout the fermentation period. In the fermented starch groups compared to the carbohydrate-free control group, while the number of *Bifidobacterium, Firmicutes* and *Bacteroidetes*increased, the number of *Proteobacteria, Actinobacteria, Faecalibacterium* and *Verrucomicrobia* decreased	(Cui et al. 2021)

Table 4 (continued)

Food source	Type of the experiment	Method	Results	References
Lotus seed	In vitro	In the study, resistant starch (20 g/l) obtained from lotus seed was fermented with fecal samples collected from healthy 8-week-old mice, and microbiota composition and the amount of SCFA determined through HPLC analysis were investigated	At the end of the study, it was stated that the number of *Lactobacillus, Allobaculum, Clostridium, Bacteroides* and *Prevotella*in the microbiota composition increased when resistant starch was added	(Li et al. 2021)
Lotus seed	In vitro	The prebiotic capacities of type III resistant starch varieties obtained from lotus seed through three different ways were compared with glucose and high amylose corn starch. In this study, in which *Bifidobacterium spp.* was used as a probiotic strain, resistant starch varieties were added to the growth medium as a carbon source	After the 48-h fermentation in which *Bifidobacterium spp.* was used, resistant starches obtained from lotus seed were more effective on the growth of bifidobacteria than were glucose and high amylose corn starch. After the 48-h fermentation, the amount of resistant starch providing optimum growth conditions was 20 g/l	(Zhang et al. 2014)
Lotus seed	In vitro	The prebiotic capacities of the two main fractions of resistant starch obtained from lotus seed were compared with those of glucose and high amylose corn starch. In the study, in which *B. adolescentis* and *L. acidophilus* were used as probiotic strains, resistant starch varieties were added to the growth medium as a carbon source	After the 48-h fermentation in which *B. adolescentis* and *L. acidophilus* were used, it was found that resistant starch with 20% concentration had a higher prebiotic capacity on the proliferation of *B. adolescentis* and *L. acidophilus* than did amylose cornstarch with ≥ 30% concentration	(Zeng et al. 2018a, b)
Lotus seed	In vitro	Glucose as carbon source, three different type III resistant starches obtained from lotus seed and high amylose cornstarch and *B. longum* and *L. delbrueckii subsp. bulgaricus* bacteria were fermented in the MRS broth medium for 48 h. After the fermentation, SCFA and lactic acid production were investigated through GC analysis	The result of the fermentation demonstrated that the lotus resistant starch with 20% concentration stimulatedacetic acid produced by *Bifidobacterium longum* and lactic acid produced by *Lactobacillus delbrueckii subsp. bulgaricus* at a higher rate than did other carbohydrate sources. In the study, the survival rate of probiotics with lotus seed resistant starch was higher in simulated gastrointestinal solutions. However, the survival rate of probiotics with glucose and high amylose cornstarch was lower in simulated gastrointestinal solutions	(Zeng et al. 2018a, b)
Wheat	In vitro	Resistant starches were obtained from wheat which underwent the cooking-freezing process. Then, fecal samples taken from 3 healthy adult individuals were fermented with resistant starch for 24 h in vitro, and SCFA production was investigated through GC analysis	After the fermentation with resistant starch, SCFA, especially propionate, production increased, and significant increases were observed in butyrate levels in the first 8 h of fermentation. In addition, significant increases were reported in the number of *Bifidobacteria* at the end of fermentation compared to that at the baseline	(Arcila and Rose 2015)
Bananas	In vitro	Prebiotic indices were calculated by obtaining unpeeled raw banana powder (URB), peeled raw banana powder (PRB) and banana starch (BS) from locally grown bananas. While the prebiotic capacity was determined, *Lactobacillus paracasei* and *Bifidobacterium longum* were used as probiotic cultures, and *Escherichia coli* and *Clostridium perfringens* were used as enteric species	The prebiotic index of banana starch and unpeeled raw banana powder was significantly higher than was that of dextrose in the control group. The highest Lactobacillus levels were observed in probiotics including URB and BS at the 9th and 18th h of fermentation. Although all the samples stimulated the growth of probiotics, probiotics supplemented with BS and URB showed significant and highest growth rates between 18 and 48 h	(Jaiturong et al. 2020)

Table 4 (continued)

Food source	Type of the experiment	Method	Results	References
Taro root	In vitro	The resistant starch content was increased by keeping the chips cut from the taro root in the fermentation and autoclaving-cooling process. Then, the prebiotic effect and prebiotic index of the chips obtained by fermenting with a probiotic culture consisting of a mixture of *Lactobacillus plantarum D-240* and *Leuconostoc mesenteroides SU-LS* in the MRS broth medium were calculated	The prebiotic effect and prebiotic index of the chips obtained were higher than were those of the control group, but lower than were those of inulin. The prebiotic activity analysis performed with *Lactobacillus plantarum-EPEC* and *Lactobacillus acidophilus-EPEC* revealed that the prebiotic activity of the chips was higher than was that of the control and lower than was that of inulin	(Setiarto et al. 2018)
Black-eyed peas Green banana Rice	In vitro	In this study, black-eyed peas, green banana, retrograde rice flour containing high amylose and a standard commercial resistant starch were used as resistant starch sources. Glucose and fructooligosaccharide (FOS) formed the control group. Probiotic cultures (*Lactobacillus acidophilus TISTR 1338* and *Lactobacillus delbrueckii subsp. bulgaricus TISTR 895*) were fermented with 1% resistant starch in the MRS broth medium	The highest resistant starch content was determined in commercial starch, followed by green banana, retrograde rice and black-eyed peas respectively. After 48 h of fermentation, live *L. acidophilus TISTR 1338* populations grown on green banana flour, retrograde rice flour, standard resistant starch and FOS increased compared to their growth at 24 h; however, those grown on black-eyed peas and glucose decreased further. However, in L. Bulgaricus probiotic, after 48 h of fermentation, no significant difference was observed between resistant starch sources. However, the comparison of viable cells incubated between 24 and 48 h revealed that retrograde rice flour, green banana flour, and glucose had viable *L. bulgaricus TISTR 895* cells	(Dangsungnoen et al. 2012)
Tropical palm trunk	In vitro	In this study, 18 *lactobacillus* and 5 *bifidobacteria* strains isolated from fermented foods or obtained commercially, and various pathogen species were used. In the study, in which glucose, FOS and natural starch were used as the control group, sago starch (Sago RS, HCL-Sago RS) isolated from the tropical palm trunk was added to the MRS broth medium as a carbon source and the proliferation of the strains was investigated	Resistant starch obtained from sago starch promoted the growth of both beneficial (*Lactobacillus* and *Bifidobacteria*) and pathogenic bacteria (*Escherichia coli, Campylobacter coli* and *Clostridium perfringens*). The highest prebiotic activity score was obtained from *Bifidobacterium sp FTDC8943*, which showed the highest activity in sago RS and HCL-sago RS, and from *L bulgaricus FTDC1511* grown in sago resistant starch	(Zi-Ni et al. 2015)
Lemantak (native sago starch)	In vitro	In this study, natural, commercialized, retrograde sago and tapioca starch were fermented with *Lactobacillus acidophilus* and *Bifidobacterium animalis*. In vitro fermentation was carried out at 37 °C for 24 h under anaerobic conditions, and total bacterial counts were calculated at 0, 6, 12, and 24 h	The highest resistant starch content was observed in natural sago starch (62.61%). It was observed that sago starch was the most preferred fermentation substrate with the highest total bacterial count at all bacterial counting hours	(Arshad et al. 2018)
Wheat Potato Pea	In vitro	In this study, the fermentation of naturally and physically modified wheat, potato and pea starches (1%) with 16 different Bifidobacterium strains was investigated. Glucose (1%) was used as the control group and in vitro fermentation was carried out at 37 °C for 24 h under anaerobic conditions	It was observed that *B. pseudolongum KSI9, B. animalis KS20a1* and *B. breve KN14* strains had the highest growth rates in both natural and modified forms of wheat, potato and pea starches. There was a significant decrease in the resistant starch content of natural and modified forms of pea and potato starches after their 24-h fermentation by *Bifidobacterium* strains	(Soral-Śmietana et al. 2005)

Table 4 (continued)

Food source	Type of the experiment	Method	Results	References
Raisin puree	In vitro	In this study, resistant starch content and probiotic viability were investigated by adding raisin puree to yogurt made from coconut milk at different rates (0%, 17%, 23% and 29%). Normal yogurt was used as the control, and *Lactobacillus acidophilus* (10^9 CFU/mL), *Lactobacillus salivarius* (10^9 CFU/mL), *Bifidobacterium bifidum* (10^9 CFU/mL) and *Streptococcus thermophiles* (10^9 CFU/mL) were used as probiotic supplements	At the end of the study, the resistant starch content of yogurts to which raisin puree was added showed a linear increase in parallel with the rates of the raisin puree added. The probiotic viability of yogurts made from coconut milk showed a linear increase in parallel with the rates of resistant starch content added. The probiotic viability of normal yogurt was similar that of yogurt to whichraisin puree was added by 29%	(Amirah et al. 2020)
Lotus seed	In vitro	In this study, in which glucose, inulin and waxy cornstarch were used as the control group, the fecal microbiota tolerance of resistant starch obtained from lotus seed was investigated. Two g feces samples taken from healthy 8-week-old mice were fermented using glucose, inulin, waxy cornstarch and lotus seed resistant starch as carbon sources (20 g/l)	While operational taxonomic units and diversity indices increased in groups given lotus seed and inulin, they decreased in glucose and corn starch. Lotus seed resistant starch promoted the proliferation of *Lactobacillus*, which uses bile acids and inhibits the growth of harmful bacteria (*Enterococcus and Staphylococcus*). Lotus seed resistant starch increased the bile salt tolerance of the fecal microbiota of mice by promoting the proliferation of bacteria utilizing bile acid and inhibiting the growth of harmful bacteria	(Lei et al. 2020)
Potatoes	In vitro	In this study, stable isotope-labeled potato starch with feces samples from mice was subjected to in vitro fermentation (at 37 °C for 2–4 h) in anaerobic conditions. RNA-based stable isotope search was performed to identify populations of bacteria involved in the fermentation of resistant starch	It was reported that *Bacteroidetes*, especially *Prevotellaceae* genera and members of *Ruminococcacea family* were prevalent among bacteria using resistant starch in RNA samples isolated after 2 h of incubation	(Herrmann et al. 2017)
Jackfruit Seeds	In vitro	Glucose (20 g) and resistant starch (20 g) obtained from jackfruit seeds were separately subjected to fermentation with *B. pseudolongum* for 48 h on the MRS agar in anaerobic and in vitro conditions	After 48 h of fermentation, the average growth of *B. pseudolongum* reached 6Log CFU/mL in the resistant starch agar medium whereas the average growth of the glucose control group was 7 log CFU/mL	(Zhang et al. 2021)
Wheat Peas Sweetcorn Potatoes Rice	In vitro	Natural starches obtained from corn (including low, normal and high amylose), rice (including normal and low amylose), wheat, peas and potatoes were subjected to fermentation in feces collected from pig rectum ($n=3$). After 72 h of fermentation, the production of SCFA was investigated through GC analysis	In chemical analysis, it was observed that pea, potato and high amylose cornstarch had the highest resistant starch content. In terms of total SCFA production, no significant difference was found between the foods. While the highest acetate production was observed in high amylose cornstarch, the highest values in butyrate production were observed in pea and potato starches	(Giuberti et al. 2013)

Table 4 (continued)

Food source	Type of the experiment	Method	Results	References
Cowpea	In vitro	In this study, resistant starches (0.5 g) obtained from five cowpea cultivars andthe probiotic culture containing 1 ml of *Bifidobacteria animalis (ATCC 25,527), Lactobacillus casei (ATCC 334), Escherichia coli (ATCC 35,150), Enterococcus faecalis (ATCC 14,506)* and *Streptococcus faecalis (ATCC 29,212)* were subjected to fermentation for 24 h	Resistant starch content of cowpea cultivars varied between 9.3% and 12.1%. After fermentation, the cowpea sample containing moderate content of resistant starch met the prebiotic classification criteria. This cowpea cultivar met the criteria for resisting digestion in the upper gastrointestinal tract, being fermented by the gut microbiota in the colon, and allowing the growth of beneficial bacteria *Lactobacillus* and *Bifidobacteria*	(Rengadu et al. 2020)
Potatoes	In vivo	Type III retrograde maltodextrin and retrograde potato starches obtained from potatoes added to the diet of the rats were consumed by the rats for 70 days. The control group had a resistant starch-free diet. At the end of the study, samples were collected from the cecum, colon and feces, pH levels were determined and SCFA production was investigated through the GC analysis method	The pH in the cecum and colon in both groups given resistant starch was lower than was that in the control group. However, pH was significantly lower in the group that consumed retrograde maltodextrin. On the other hand, SCFA production in cecal and colonic contents was higher in the groups given resistant starch than was that in the control group	(Dongowski et al. 2005)
Sago starch	In vitro	Type III resistant starch was obtained from natural sago starch by autoclaving, cooling and tempering. Type III sago resistant starch was fermented at 37 °C for 24 h with *L. acidophilus FTCC 0291, L. bulgaricus FTCC 0411, L. casei FTCC 0442* and *B. bifidum BB12*, and the amount of SCFA was investigated by pH and GC analysis. Comparisons were made with commercial FOS, Hi-maize 1043 and Hi-maize 240 resistant starches	Sago resistant starch was fermented at concentrations ranging from 1.25 to 7.5 g/l. Bacterial growth levels were significantly higher in the group given sago resistant starch compared to the group given commercial carbohydrates. As the amount of sago resistant starch increased, so did the total number of live bacteria and carbohydrate consumption and there was a significant decrease in pH in the environment. The analysis of SCFA amounts demonstrated that the highest production was in FOS, followed by Hi-Maize 240, Hi-Maize 1043 and sago resistant starch, respectively	(Siew-Wai et al. 2010)
Purple yam	In vitro	The following three resistant starches were obtained from freshly harvested purple yam: DAS (dual autoclaving-retrogradation starch), PDS (pullulanase debranched starch), and PDS.H (PDS hydrolyzed by α-amylase and amyloglucosidase). The control group, glucose group and resistant starch group were exposed to fermentation with *Bifidobacterium adolescentis* for 24 h, and the amount of SCFA through GC analysis method and prebiotic capacity were investigated	The tolerance test demonstrated that in simulated upper gastrointestinal conditions, *bifidobacteria* adapted to the media containing PDS and PDS.H resistant starch better than they adapted to the media containing glucose and DAS resistant starch. While the growth phase of *bifidobacteria* was 2 h in the medium containing PDS or PDS.H, it was 4 h in the medium containing glucose or DAS. In the production of SCFA, the highest values were reached in the PDS.H medium	(Li et al. 2018)

Table 4 (continued)

Food source	Type of the experiment	Method	Results	References
Lotus seed	In vitro	In the first stage of the study, resistant starch was obtained from the lotus seed by retrogradation. Fecal samples collected from healthy rats were fermented with the obtained resistant starch. Glucose and high amylose cornstarch were used as the control group. In the study, the conversion of lactic acid to butyric acid was investigated by using isotope lactic acids whereas the amount of SCFA, and enzyme activities were investigated through HPLC analysis	The microbiota in the resistant starch group had higher abundance and diversity than did glucose and high amylose corn starch. Resistant starch and isotope lactic acid promoted the growth of *Lactobacillus* and *Bifidobacterium* and the production of butyric acid but inhibited the growth of *Escherichia – Shigella*. Lotus seed resistant starch especially increased the conversion of lactic acid to butyric acid in the gut microbiota, including *Allobaculum, Bifidobacterium* and *Ralstonia*	(Wang et al. 2022a, b)
Purple yam	In vitro	Two types of resistant starch were obtained from purple yam starch through heat-moisture treatment (HMT) and enzyme debranching combined heat-moisture treatment (EHMT). In the study, while glucose was used as negative control, high amylose corn starch was used as positive control. The carbon source concentration of 5–40 g/l was fermented with *Bifidobacteria* at 37 °C for 50 h	While the resistant starch content of purple yam was 5%, resistant starch content obtained through HMT was 14.2% and resistant starch content obtained through EHMT was 17.1%. After 50 h of fermentation, the highest *Bifidobacteria* concentration was observed at 20 g/l. In terms of prebiotic capacity, the highest *Bifidobacteria* growth was observed in resistant starch obtained through EHMT followed by resistant starch obtained through HMT, high amylose corn starch and glucose	(Zheng et al. 2016)
Cowpea	In vitro	In this study, the viability and stability of *Lactobacillus casei ATCC 334* and *Bifidobacterium animalis ATCC 25,527*, which are probiotic bacteria, encapsulated with cowpea resistant starch obtained by freeze drying, were assessed	At the end of 28 days, when resistant starch was encapsulated with probiotic bacteria, the final bacterial viability in the microcapsules was significantly higher than the microcapsules containing only bacteria	(Rengadu et al. 2021)
Tapioca Sweet corn Waxy Corn	In vitro	Natural starches and retrograde starches obtained from tapioca, sweetcorn and waxy corn were fermented with Bifidobacterium strains (*Bifidobacterium pseudolongum KSI9, Bifidobacterium breve KN14* and *Bifidobacterium animalis KS20a1*) at 37 °C for 24 h. In the study, glucose was used as the control group	Resistant starches (retrograde) obtained from normal and waxy corn starches were the best substrates for the growth of *B. breve KN14* compared to glucose. While the highest resistant starch utilization rate for the *bifidobacterium pseudolongum KS19* probiotic was observed in retrograde tapioca and corn starch, the highest resistant starch utilization rate for the *bifibacterium breve KN14* and *bifidobacterium animalis KS20a1* probiotic was observed in retrograde corn starch. Retrograde starches stimulate the growth and acidification activity of *B. pseudolongum KSI9* better than do natural starches	(Wronkowska et al. 2008)
Lotus seed	In vitro	Two types of resistant starch (LRS3 and P-LRS3) obtained from lotus seed, and glucose and high amylose corn starch determined as control were subjected to fermentation with *B. adolescentis* for 48 h. The carbon source concentration varied between 1.25–40 g/l, and the amount of SCFA was investigated by ultra-performance liquid chromatography analysis after fermentation	*Bifidobacteria* had higher tolerance to gastrointestinal conditions on the LRS3 and P-LRS3 media compared to the media containing glucose and high amylose corn starch. The growth rate of bifidobacteria was higher in the media containing LRS3 and P-LRS3 at 48 h than was that in the media containing glucose and high amylose corn starch. The highest bacterial growth rate and butyric acid production were observed in the medium containing P-LRS3	(Zhang et al. 2013)

Table 4 (continued)

Food source	Type of the experiment	Method	Results	References
Breadfruit	In vitro	The prebiotic activity scores of flour, resistant starch (type III) and inulin obtained from breadfruit were evaluated in vitro. *Lactobacillus plantarum ATCC 8014, Bifidobacteria bifidum ATCC 11,863* and *Escherichia coli ATCC 10,536* were used for fermentation, and the fermentation time was determined as 72 h. Glucose was used as the control group	The highest prebiotic score (0.45) was obtained after 12 h of fermentation for *L.plantarum* bacteria using resistant starch obtained from breadfruit. However, the highest prebiotic score (0.65) for *B.bifidum* was observed in resistant starch obtained from breadfruit after 48 h of fermentation. For both strains, pH values after fermentation were significantly different from those determined at the baseline	(Zarinah et al. 2018)
Soy Flour	In vitro	Resistant starch obtained from soy flour was separated into nanoparticles and exposed to fermentation with *B. brevis* and *L. Casei bacteria* under anaerobic conditions at 37 °C for 72 h. The total number of viable *B. brevis* and *L. casei* on agar was calculated, and the amount of SCFA was determined through the GC analysis method	In both species, SCFA production and an increase in the growth and activity of bacteria were observed. At the end of fermentation, the growth rate of *B. brevis* increased 4.5 times, while that of *L. casei increased* 5.5 times. During SCFA production, acetate production increased in *L. casei;* however, it reached the highest level in *B. brevis*, followed by butyrate and propionate	(Sivapragasam et al. 2014)
Broad Bean	In vitro	During the first phase of the study, the ability of 20 *Lactobacillus* and 8 *Bifidobacterium* strain to hydrolyze broad bean starch was investigated. Later, *Bifidobacterium breve ATCC 15,700* and *Lactobacillus rhamnosus GG ATCC 53,103* were added to Mexican panela cheeses. Two types of fresh cheese (with 3% broad bean starch and without broad bean starch) were produced with the combination of probiotics, and probiotic viability and pH were examined at the end of the 4 weeks	At the beginning of the study, of the 28 selected species, only *Bifidobacterium breve ATCC 15,700* hydrolyzed broad bean starch. During the 4 weeks, in cheeses with and without bean starch, a decrease was observed in pH when probiotics were given alone or in combination, but no significant difference was observed. During the 4 weeks, while the number of bacteria increased in cheeses with and without bean starch in *L. rhamnosus* and the combination of probiotics, the number of *B. breve* decreased. However, no significant difference was observed	(Escobar et al. 2012)

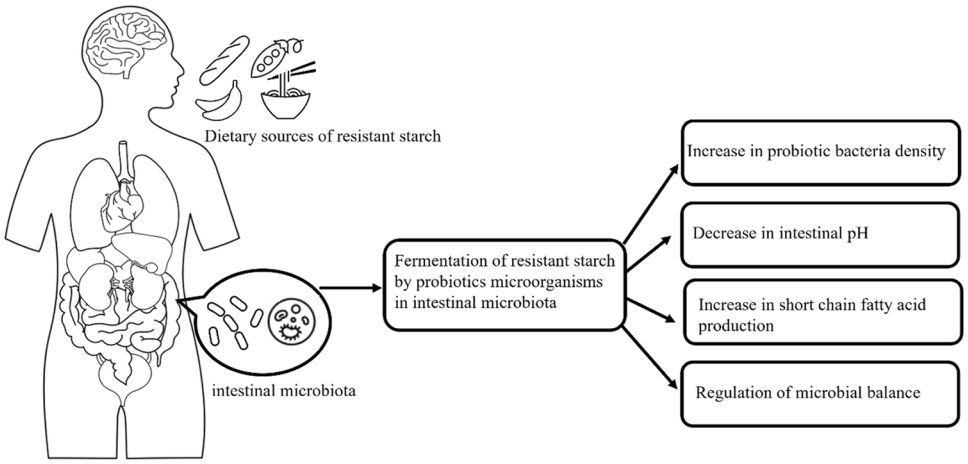

Fig. 1 The relationship between resistant starch and probiotics in intestinal microbiota

resistant starch in faeces was investigated, and fermentability of resistant starch (in humans) was investigated by a hydrogen breath test. Based on the analysis of studies in general, it is possible to say that resistant starch can be fermented by the microbiota and that SCFAs increase with resistant starch fermentation in humans and other living things ((Bojarczuk et al. 2022; Zaman and Sarbini 2016). According to the analysis of studies in which the capacity of resistant starch in terms of selective stimulation of the growth and/or activity of healthy gut bacteria was investigated, it was found that type II resistant starch stimulated the growth of *Bifidobacterium* and *Bacteroidetes* in mice (Tachon et al. 2013), that type III resistant starch stimulated *Bifidobacterium* growth and increased SCFA production in in vitro applications (Purwani et al. 2012), that type IV resistant starch changed the profile of bacterial communities in vitro applications (Erickson et al. 2018), and that type IV resistant starch increased SCFA production and decreased colonic pH in a clinical study (Upadhyaya et al. 2016). In conclusion, considering all this information, it becomes certain that resistant starch has a potential prebiotic capacity, and the modulation of microbiota with resistant starch attracts a great deal of attention in the field of modern nutrition.

The prebiotic capacity of resistant starch types isolated from foods

The literature review revealed that resistant starch types which are both isolated from food and produced commercially are used in resistant starch applications. The review of studies conducted on resistant starch isolated from foods demonstrated that in those studies, foods with high starch content such as potatoes, rice, bananas, tapioca, corn, peas, and wheat were used. In addition to these nutrients, resistant starches obtained from local foods such as lotus seed, breadfruit, sago starch, and jackfruit seeds have been frequently used in studies. The type of resistant starch isolated from food is mostly type III resistant starch, followed by type II resistant starch. The studies were mostly carried out in vitro, and it is noteworthy that especially two methods are frequently preferred. In the first of these methods, isolated resistant starch is added to the basic growth medium of probiotics as a carbon source and whether it is fermented according to microbial growth this evaluated. In the second method, human or animal faeces samples and resistant starch are added to the basic growth medium and subjected to fermentation under in vitro conditions, and colonic fermentation of resistant starch is evaluated according to microbial composition or SCFA profiles. In most of the existing studies, it has been shown that there is an increase in the number and viability of probiotic cultures fermented with resistant starch and that resistant starch types isolated from foods are used as carbon sources by probiotic bacteria. In addition, in studies, it has been frequently reported that when resistant starch is fermented with probiotic culture or faeces, it increases SCFA production. Although in most of the studies, the general prebiotic effects of resistant starch types isolated from foods have been shown; in the literature, there are studies in which the prebiotic effect of resistant starch types is reported to be insufficient or ineffective. The differences between these results are thought to stem from the fact that the types of foods from which starch was isolated were different, that the type of the resistant starch was different, or that the different methods were used to produce resistant starch. In Table 4, the prebiotic capacities of resistant starch types isolated from foods are presented.

The prebiotic capacity of commercially produced resistant starch types

The review of studies involving commercially produced resistant starches demonstrated that mostly type II, type III, and type IV resistant starch were included in the studies. Of studies involving commercial resistant starches, some

Table 5 Prebiotic capacities of commercially produced resistant starch types

Resistant starch types	Type of the experiment	Method	Results	References
Hi-maize 260	In vitro	In this study, *Lactobacillus casei ATCC 39,392* was encapsulated with calcium alginate and 2 g resistant starch using the emulsion technique. Probiotic bacteria were added to the cream-filled cake in free and micro-encapsulated forms. The viability and pH changes of free and microencapsulated bacteria were monitored during 4 weeks of storage at 4 °C and 25 °C	pH changes during the storage of microencapsulated *L. casei* containing resistant starch were slower than were those in the product containing free L. casei. At low temperature (4 °C), the viability of microencapsulated *L. casei* containing resistant starch was significantly higher than was that of free bacteria and products encapsulated only with calcium alginate	(Zanjani et al. 2012)
Hi-maize	In vitro	In this study, the viability of bacteria was evaluated by adding rice bran, inulin and resistant starch to Lactobacillus acidophilus microencapsulated in alginate by external ionic gelation. The viability of the probiotics was investigated for resistance to simulated gastrointestinal conditions and stability under different storage conditions for 120 days	In all the treatments, encapsulation appeared to provide better protection for probiotics after they were exposed to simulated gastrointestinal fluid than to free culture. Live probiotics were preserved for 120 days when alginate, rice bran, and Hi-maize were added during storage under different conditions at 25 °C. Bacteria to which only inulin was added at − 18 °C remained stable for 120 days. During the 120 days of storage, rice bran and inulin preservedviable probiotics at 7 °C	(Poletto et al. 2019)
Hi-maize	In vitro	In this study, bacterial viability was observed at different temperatures for 135 days by addingresistant starch (1%) chitosan (0.4%) to the alginate microcapsule of *Lactobacillus acidophilus*with the extrusion technique. Two different microparticles, one of which was moist and the other of which was freeze-dried were investigated	After they were exposed to simulated gastric and intestinal juice, microcapsules containing resistant starch and chitosan preserved probiotics better; however, bacterial counts were lower in freeze-dried microcapsules. The bacterial count in microcapsules to which hi-maize and chitosan were added was higher at + 25 °C, − 18 °C and + 7 °C for 135 days	(de Araújo Etchepare et al. 2016a)
High amylose corn starch	In vitro	In this study, *B. adolescent P2P3*strain isolated from healthy adult feces and B. *choerinum FMB-1* strain isolated from rumen fluid of native Korean cattle were inoculated into media containing 0.5% high amylose corn starch andwere exposed to fermentation for 72 h. Genes encoding amylolytic enzymes that may be responsible for resistant starch degradation in *Bifidobacterium adolescentis P2P3* genome were investigated by comparative genomic analysis	In this study, four genes which encode the amylolytic enzymes responsible for resistant starch degradation in the *Bifidobacterium adolescentis P2P3* genome were identified by comparative genomic analysis. Study results demonstrated that in addition to typical α-amylase activity, three enzymes exhibited activity which degraded high amylose corn starch and that these enzymes might be key enzymes used by bifidobacteria that degraded resistant starch	(Jung et al. 2020)
Hi-maize	In vitro	In this study, the viability of *L. casei 01* in saliva, gastric and intestinal fluids was investigated by encapsulating it with various prebiotics (resistant starch, lactulose and lactosucrose)	At the end of the study, it was observed that the gastric tolerance degree of probiotic cells was significantly improved with the encapsulation method, even in the presence of pepsin. It was also observed that the bacteria with the highest rate of bacterial viability in saliva, gastric and intestinal fluids were in the cells encapsulated in resistant starch-alginate	(Ta et al. 2021)

Table 5 (continued)

Resistant starch types	Type of the experiment	Method	Results	References
Fibersol	In vivo	Healthy Wistar rats and Wistar rats with colitis were administered FOS (2 g), resistant starch (2 g) and FOS + resistant starch (37.5% FOS and 62.5% resistant starch = 2 g) and they were followed for 2 weeks. At the end of the follow-up, the number of *Lactobacilli and Bifidobacteria* was calculated, and the amount of SCFA was analyzed by GC analysis method	In healthy rats, administration of the combination of FOS and resistant starch caused changes in the gut microbiota by increasing lactobacilli and bifidobacteria in the cecum and colonic contents. Rats with colitis were administered resistant starch or FOS. Then, resistant starch was compared with fructooligosaccharides	(Rodríguez-Cabezas et al. 2010)
Hi-maize	In vitro	The *L. acidophilus La5* probiotic culture is encapsulated with calcium alginate and 2 g of resistant starch. Probiotic bacteria were added to cheeses in free and microencapsulated forms and the viability of the bacteria was monitored for 182 days	The number of viable cells of *Lactobacillus acidophilus* significantly declined in both cheese types from day 28 to day 182 of the storage period. However, the decline in cheese containing free probiotics was significantly higher than was that in cheese containing microencapsulated probiotics	(Mirzaei et al. 2012)
Hi-maize	In vitro	In this study, the *L. acidophilus La-14* probiotic culture was encapsulated in various ways. Moist, and freeze-dried microparticles with or without resistant starch (1%) were obtained. Bacterial viability of these capsules was investigated for 135 days at different temperatures	The results demonstrated that moist, and freeze-dried microparticles containing resistant starch provided better protection for probiotics after they were exposed to simulated gastrointestinal fluid. During the storage period, the number of viable bacteria in the moist, and freeze-dried microparticles containing resistant starch was higher than was that of the microparticles without resistant starch	(de Araújo Etchepare et al. 2016b)
Hi-maize 260 Novelose 330 Fibersym RW	In vitro	In this study, fecal samples collected from 7 healthy volunteers and resistant starch types were fermented for 24 h. Corn starch was used as negative control and FOS as positive control, and the effects of resistant starch types on individual microbiome were investigated by metaproteomic methods	At the end of the study, it was observed that type II and type III resistant starch significantly changed protein expressions in individual intestinal microbiota and that type IV resistant starch did not cause any significant protein changes. *Bifidobacteriaceae* increased significantly in response to type III resistant starch	(Li et al. 2020)
Versafibe™1490 Novelose 3490 Versafibe™2470 Versafibe™2480	In vitro	Fecal samples collected from healthy volunteers ($n = 7$) and four different type-IV resistant starches obtained by chemical modification were subjected to 24-h fermentation, and pH values, SCFA determined with the GC analysis, andthe amount of gas determined with the syringe difference analysis method were investigated. Polydextrose and short chain FOS were used as the control group	At the end of the study, it was observed that all compounds could be fermented and that they supported the formation of SCFA. While Versafibe™1490 and Novelose 3490 resistant starches led to similar gas and SCFA production, Versafibe™2470 and Versafibe™2480 resistant starches led to higher pH, lower gas and acetate production	(Erickson et al. 2018)
High amylose corn starch	In vitro	Type III resistant starch obtained from high amylose cornstarch through gelatinization and heat-moisture application was fermented with feces samples collected from healthy individuals ($n = 3$) for 24 h and the amount of SCFA determined by GC analysiswas investigated. High amylose cornstarch was selected as the control group	At the end of fermentation with type III resistant starch, SCFA, butyric and propionic acid production increased significantly. In the first stage fermentation, high amylose cornstarch fermented faster than did type III resistant starch. However, it was observed that type III resistant starch produced SCFA more than did high amylose cornstarch	(Chang et al. 2021)

Table 5 (continued)

Resistant starch types	Type of the experiment	Method	Results	References
Fibersym RW	In vivo	Adult Wistar rats ($n=24$) were divided into three groups. One of the groups was the control group. One of the other two groups had a diet containing resistant starch whereas the other group was fed with bread including resistant starch for 60 days. Then the cecum, fecal contents and intestinal microbiota of the animals were investigated	The group which consumed bread containing resistant starch in the diet had higher satiety and lower food consumption levels than did the other groups. In the groups consuming resistant starch, the *Lactobacillus* count was higher, and better intestinal balance was achieved	(Correa et al. 2020)
Hi-maize 240 Hi-maize 958 Novelose 330	In vitro	Fecal samples were collected from healthy adult individuals ($n=3$), and *Eubacterium rectale A1-86 T, Ruminococcus bromii L2-63* and *Bifidobacterium adolescentis L2-32* strains were isolated. *Bacteroides thetaiotaomicron 5482 (ATCC 29,148), R. bromii 27,255* and *B. breve 20,213* strains were obtained from ATCC. Resistant starch types as carbon source were added to the media and the degradation of resistant starch of probiotic strains was investigated	The comparison of *Eubacterium rectale* and *Bacteroides thetaiotaomicron*with *Bifidobacterium adolescentis and Ruminococcus bromii* demonstrated that type II and type III resistant starches had limited degradation efficacy. *Ruminococcus bromii* strain degraded both type II and type III resistant starches. In addition, *Ruminococcus bromii* strain increased type III resistant starch fermentation in the in vitro application	(Ze et al. 2012)
Hi-maize 260	In vitro	In this study, the viability of Lactobacillus rhamnosus LBRE-LSAS isolated from healthy newborns and probiotic *Bifidobacterium animalis subsp lactis Bb12 (ATCC 27,536)* in simulated saliva, gastric and intestinal fluids after their encapsulation with calcium alginate and resistant starch were investigated. Then, after free and encapsulated bacteria and yogurt cultures were prepared, bacterial viability was investigated during 4 weeks of storage	In the study, the survival rates of encapsulated cells were significantly higher than were those of free cells. Microencapsulation enabled bacteria to survive better, which led to higher production of exopolysaccharides in yogurts stored at 4 °C	(Ziar et al. 2012)
High amylose corn starch	In vitro In vivo	*Bifidobacterium spp. LaftiTM 8B* and *LaftiTM 13B* bacteria isolated from feces samples collected from healthy individuals were grown in a broth medium containing glucose or 1% high amylose cornstarch andproliferation of the strains was investigated. In the in vivo phase of the study, the rats were divided into 3 groups. While one of the groups had a normal diet, another group had a diet containing a moderate amount of high amylose corn starch and the other group had a diet containing a high amount of high amylose corn starch, and bacterial counts were calculated	At the end of the study, the survival rate of *LaftiTM 8B* and *LaftiTM 13B* strains increased in the presence of high amylose corn starch. After the oral administration of bacterial strains to rats, it was observed that the amount of *LaftiTM 8B* strain in fecal samples collected from rats fed with a high-amylose corn starch diet was six-fold higher than was that in controls. High amylose corn starch granules promoted the survival of *Bifidobacterium spp., LaftiTM 8B and LaftiTM 13B* strains	(Wang et al. 1999)

Table 5 (continued)

Resistant starch types	Type of the experiment	Method	Results	References
Hi-maize 240 Hi-maize 1043	In vitro	In this study, in vitro fermentation of type II resistant starches, sago starch, which is type III resistant starch, and FOS were investigated. Resistant starches were fermented with *Lactobacillus acidophilus FTCC 0291, Lactobacillus bulgaricus FTCC 0411, Lactobacillus casei FTCC 0442* and *Bifidobacterium bifidum BB12* at 37 °C for 24 h, and pH levels calculated and the amount of SCFA determined by GC analysis were investigated	Bacterial growth levels were found to be significantly higher in the group given sago resistant starch than were those in the group given commercial carbohydrates. As the amount of sago resistant starch increased, the total number of live bacteria and carbohydrate consumption increased, and pH in the environment decreased significantly. When SCFA production was examined, the highest production was observed in FOS, followed by Hi-Maize 240, Hi-Maize 1043 and sago resistant starch, respectively	(Siew-Wai et al. 2010)
Hi-maize 260 Hi-maize 958 Novelose 330 Versafibe 1490 Versafibe 2470 S4180	In vitro	Bacteria in the intestinal microbiota that could degrade resistant starch were isolated by fermenting resistant starches with feces samples collected from a healthy adult individual. In addition, bacterial degradation of resistant starch was investigated by fermenting resistant starches with a probiotic culture consisting of *Bacteroides thetaiotaomicron (ATCC 29,148), B. adolescentis (DSM 20,083, DSM 20,086, DSM 20,087,* and *DSM 24,849), B. adolescentis P2P3* and *Bifidobacterium adolescentis L2-32* strains	It was observed that resistant starch was degraded by *B. adolescent P2P3,* and that the carbon source produced was used by *Bacteroides thetaiotaomicron ATCC 29,148.* It was determined that *Bifidobacterium adolescentisP2P3* strain degraded the high amylose corn starch up to 63.3%. It was observed that while *B. adolescentis DSM 20,087, DSM 24,849* and *L2-32*could use approximately 9.8%, 47.3% and 43.8% of resistant starch, respectively, *DSM 20,083* and *DSM 20,086* strains did not break down resistant starch at all. *B. adolescentis P2P3 HM 260, HM 958, NV 330, VF 1490* and *VF 2470* used 37.3%, 69.6%, 44.5%, 51.6% and 54.4% of resistant starches respectively	(Jung et al. 2019)
Novelose 330	In vitro	In thisstudy, new lactic acid bacteria strains of the genus *Bifidobacterium* were screened by the 16S rRNA method in feces samples collected from healthy adult individuals ($n=3$). The degradation of resistant starch by bacteria was investigated by adding resistant starch to the media as a carbon source	When the use of type III resistant starch as a carbon source was examined, it was observed that Bifidobacterium adolescent strains of *B. adolescentis JCS2* and *JCS16* degraded type III resistant starch	(Kim et al. 2018)
Hi-maize 958 S4180	In vitro	In this study, the use of resistant starch by bacteria in the liquid obtained from cattle rumen was investigated in vitro. Microorganisms reducing resistant starch were identified and isolated by metagenomic means. *E. rectale (DSM 17,629), Bac.thetaiotaomicron (ATCC 29,148), L. brevis (ATCC 14,869)* and *B. choerinum FMB-1* were used as reference bacteria	The major microbial genus in a general rumen fluid was *Succiniclasticum sp.*; however, after the addition of resistant starch, *Streptococcus sp.*became dominant. Then *Lactobacillus sp*. became predominant and the presence of *Bifidobacterium sp.*was observed. In this study, it was observed that *B. choerinum FMB-1* and *B. pseudolongum FMB-2 strains*could degrade resistant starch. *B. choerinum FMB-1* hydrolyzed resistant starch at the highest rate and could degrade almost 60% of all substrates tested	(Jung et al. 2018)

Table 5 (continued)

Resistant starch types	Type of the experiment	Method	Results	References
Versafibe 1490 Versafibe 2470 Versafibe 2480 Novelose 3490	In vivo	In this study, 40 Sprague–Dawley rats were divided into 5 groups, one of which was the control group. Except for the control group, a 3-week nutrition plan was applied to each group, with 10% of the diet being a different type of resistant starch. At the end of the study, the amount of SCFA of the cecum and cecal contents of the rats was examined by GC analysis method. The pH of the cecum and cecal contents of the rats was measured	As a result of the study, the pH value of the cecum was lower in the rats fed with VF2470, VF2480 and NV3490 compared to the rats fed with control and VF1490; cecum wet weight, acetate and propionate production were found to be higher. Butyrate values were found to be numerically higher for VF1490, VF2470 and VF2480 when compared to control and NV3490, but no statistically significant difference was found	(Coulon et al. 2020)
Hylon VII Crispfilm Modified high amylose corn starch	In vitro	In this study, fecal samples were collected twice from 17 healthy infants, before they stopped breastfeeding and 10 weeks after they started solid feeding. The collected samples and resistant starches were incubated for 24 h and the amount of SCFA determined through GC analysis pH values, and microbial composition, were investigated	Fecal samples collected before stopping breastfeeding were incubated with resistant starch. No substrate was added to the samples determined as the control group. After 24 h of incubation, in fecal samples to which resistant starch was added, a significant decrease in pH levels and a significant increase in total SCFA production were observed. It was found that resistant starch fermentation and Shannon's diversity index increased in samples collected from the infants after they were started solid foods. This was associated with the increased number of *Bifidobacterium* and *Bacteroides*	(Gopalsamy et al. 2019)
Hi-maize 958	In vivo	In this study, Sprague–Dawley rats had diets of lyophilized cultures of *Lactobacillus acidophilus* and/or *Bifidobacterium lactis* at 1% concentration with 10% resistant starch orwithout resistant starch for 4 weeks. At the end of the study, SCFA determined by GC analysis method, cecal bacteria count, fecal and cecal pHlevels, and cell proliferation were investigated	In rats fed with bacterial cultures and resistant starch, fecal pH increased. In rats fed with resistant starch, cell proliferation and crypt column height increased. In rats fed with resistant starch, SCFA levels, and the number of *bifidobacteria* and *lactobacillus* species increased, while pH levels and total coliform counts decreased	(Le Leu et al. 2005)
Hi-maize	In vitro	In this study, in vitro screening was performed to select the probiotic *Bifidobacterium* strain that can be fermented with resistant starch to make synbiotic yogurt. Forty bifidobacterium strains and resistant starch were fermented at 37 °C for 3 days. Then, synbiotic yogurt was prepared with the determined bacteria and resistant starch. The prepared yogurt was stored at 4 °C for 6 weeks and bacterial viability was monitored	It was observed that *Bifidobacterium adolescentis ATCC 15706a, ATCC 15706b, ATCC 15,705, ATCC 157,063, ATCC 15,704, B7420, B74, B74A, B97; Bifidobacterium angulatum ATCC 27,535; Bifidobacterium bifidum ATCC 15,696, DSM 20,082, DSM 20,215, B7298; Bifidobacterium breve ATCC 15,699, ATCC 15,698, NCIMB 8807, B32, CIP 6468; Bifidobacterium infantis ATCC 15,697, Bifidobacterium lactis Lafti™B94; Bifidobacterium longum B612, B21, B21C* and *Lafti™B22* could hydrolyze resistant starch. However, among bacteria, only *B. lactis Lafti™B94* had all the necessary properties. This isolate preserved its vitality in conditions simulating the passage through the gastrointestinal tract and has technological properties suitable for yogurt production. *Bifidobacterium lactis Lafti™B94* survived in synbiotic yogurt containing Hi-maize stored at 4 °C for 6 weeks without significant loss of viability	(Crittenden et al. 2001)

Table 5 (continued)

Resistant starch types	Type of the experiment	Method	Results	References
High amylose corn starch	In vitro	In this study, firstly, type IV resistant starch was obtained from high amylose cornstarch through chemical modification. Synbiotic yogurt was prepared by encapsulating the obtained resistant starch with pure culture of *Bifidobacterium breve ATCC 15,700*. The viability of the encapsulated and freely added bacteria in the prepared yogurts stored at 4 °C for 4 weeks was investigated	During fermentation, the number of probiotic cells in yogurt increased compared to that at the onset. Microencapsulated bacteria had higher survival rates than did free cells during storage and after exposure to simulated gastrointestinal conditions. Type IV resistant starch, when added at 10%, protected cells as much as whey protein did	(Murúa-Pagola et al. 2021)
Hi-maize™	In vivo	In this study, 4-week-old ob/ob mice ($n=30$) were assigned into five groups. After the groups were fed with normal diet, high-fat diet, dietsincluding 10% (low), 15% (moderate) and 20% (high) resistant starch for 12 weeks, the microbiota content of the animals, and the amount of SCFA determined throughthe GC analysis methodin the feces were investigated	While the high-fat diet group and control group had the least similarity in terms of microbiota content, the control group and the group consuming high resistant starch had the highest similarity. In terms of *Bacteroidetes* and *Firmicutes*rates, a significant difference was observed only between the group that consumed high-fat diet and the group that consumed high resistant starch. While the concentration of SCFA measured in feces was the lowest in the high-fat diet group, it significantly increased in groups given resistant starch	(Wang et al. 2019)
Hi-maize 260	In vivo	In this study, 18-month-old mice ($n=18$) divided into three groups: control group, high-fat diet group and high-fat + 20% resistant starch diet group. After the groups were fed for 16 weeks, their microbiota content was investigated with the 16S rRNA method, and the amount of SCFA in the colon was investigated with the GC analysis method	The analysis ofthe fecal microbiota demonstrated that resistant starch reduced the density of pathogen taxa including *Desulfovibrio (Proteobacteria phylum), Ruminiclostridium 9, Lachnoclostridium, Helicobacteria, Oscillibacter, Alistipes, Peptococcus and Rikenella* which were associated with obesity, inflammation and aging. In the resistant starch group, while colonic butyric acid production increased 2.6 times compared to that in the high-fat diet group, Isobutyric and isovaleric acid levels decreased by half	(Zhang et al. 2020)
Novelose 330	In vivo	In the first stage of the study, a new resistant starch product (HMT-Novelose 330) was obtained by subjecting the Novelose 330 resistant starch product to heat-moisture treatment. Wistar rats ($n=15$) were divided into three groups: control diet group, Novelose 330 diet groupand HMT novelose 330 diet group. The groups were fed 25 days. At the end of the study, the amount of SCFA in the groups was investigated with the GC analysis method	Novelose 330 fermentation was more dominant in the proximal colon, HMT-Novelose 330 fermentation was more dominant in the distal colon, resulting in higher butyrate production in this part of the large intestine. In rats fed with diet containing Novelose 330, intestinal surface and crypt length increased in the proximal colon, and the crypt length reached maximum values in the distal segment after uptake of HMT-Novelose 330. In rats fed with type III resistant starch, cecal and colonic contents had lower pH levels and higher butyrate concentrations	(Jacobasch et al. 2006)

Table 5 (continued)

Resistant starch types	Type of the experiment	Method	Results	References
Novelose 330	In vivo	In the study, rats were divided into 6 groups each of which included 10 rats: control group, oat flour diet group, oat bran diet group, oat flour + novelose 330-dietgroup, oat bran + novelose 330-dietgroup and autoclaved oat flour diet group. The groups were monitored for 6 weeks. At the end of the study, the amount of SCFA of the groups was investigated with the GC analysis method	While the number of *Bifidobacteria* was higher in the test groups, coliform count was lower. The mass and content of the cecum wall were significantly higher in the groups fed with diets including Novelose and bran. Intestinal content, acetate, propionate, butyrate and total SCFA production were higher in all the test groups compared to those in the control group	(Drzikova et al. 2005)
Hylon VII	In vitro	In the first stage of the study, two type-III resistant starch polymorphs, named A and B, were produced by subjecting Hylon VII resistant starch to heat-moisture treatment. In the second stage of the study, feces samples collected from healthy adult individuals ($n=3$) and resistant starches were subjected to fermentation for 24 h. FOS was used as the control group and the amount of SCFA was investigated via the GC analysis method	Of the resistant starches, while *Bifidobacterium spp*. induced polymorph B, *Atopobium spp*. induced the polymorph A. Polymorph B induced butyrate production more than did other resistant starch types. At the end of the fermentation, the highest total bacterial count was observed in polymorph B, FOS, polymorph A and Hylon VII, respectively. At the end of the fermentation, the highest acetic acid production was observed in polymorph A whereas the highest propionic acid production was observed in polymorph B. Polymorph B promoted the growth of bifidobacteria in the proximal colon and doubled the relative proportions of microbiota in the distal colon	(Lesmes et al. 2008)
HylonVII (Acetylated) HylonVII (Butyrylated) Hi-maize 260 Hi-maize 1043 Novelose 3490	In vitro	Resistant starches, and feces samples collected from healthy adult individuals were subjected to fermentation for 4 h at 37 °C in vitro ($n=3$). After the fermentation, pH levels, total gas production with pressure sensors, and SCFA production determined with the GC analysis method were investigated. Fiber types such as inulin, FOS, carrot fiber, xylooligosaccharide and methylcellulose were also included in the study	In terms of total gas production, among the resistant starches with the highest production were Hi-maize 260, Hi-maize 1043, Hylon VII (Acetylated), Novelose 3490 and Hylon VII (Butyrylated). However, gas production by FOS, xylo-oligosaccharide, inulin and carrot fiber was significantly higher than was gas production by resistant starches. In terms of total SCFA production, among resistant starches with the highest production were Hi-maize 260, Hi-maize 1043, Hylon VII (Acetylated), Novelose 3490 and Hylon VII (Butyrylated). However, SCFA production by FOS, xylo-oligosaccharide, inulin and carrot fiber was significantly higher than was SCFA production by resistant starches. A higher decrease in pH was observed in resistant starch fermentation compared to that in the other fibers	(So et al. 2021)

Table 5 (continued)

Resistant starch types	Type of the experiment	Method	Results	References
Type II Type IV	In vitro	In this study, in vitro fermentation was investigated by adding type II and type IV resistant starch to instant dehydrated rice noodles. Twenty percent type II resistant starch and 0.15% carboxymethyl cellulose (CMC) were added to rice noodles instead of rice flour, and 25% type IV resistant starch and 0.15% CMC were added to the second formulation. Formulations prepared with fecal samples collected from healthy adult individuals ($n = 5$) were investigatedin terms of intestinal health function	After 24 h of fermentation, a significantly higher number of *Bifidobacteria* were obtained from the formulations containing resistant starch compared to the control. The prebiotic indexes of type II and type IV resistant starches were 3.8 and 2.8 times higher respectively than was those of the control during 24-h fermentation. The total SCFA, butyric, acetic and propionic acid production of formulations containing resistant starch were higher than was that of the control. However, the results obtained were not statistically significant	(Alfhlasari et al. 2021)

have been conducted in vitro, and some have been conducted in vivo. In in vitro studies, probiotic bacteria were microencapsulated, and resistant starch was added to microencapsulated probiotic bacteria to investigate the effect of resistant starch on the number and viability of encapsulated probiotic bacteria. In vivo studies were carried out in MRS broth medium by examining the co-fermentation of probiotic cultures or animal/human faeces samples with resistant starch. In in vitro studies, the prebiotic effects of resistant starch were investigated by adding resistant starch to the diet at a per cent rate by using animal models. In in vitro studies, it was observed that the number of probiotic cultures fermented with commercial resistant starch increased, and SCFA production increased when commercial resistant starch was fermented with probiotic culture or faeces. In microencapsulation studies, it has been shown that encapsulation of probiotic bacteria together with commercial resistant starch may have positive effects on the viability and number of bacteria. In in vivo studies, it was observed that commercial resistant starch types modulated the microbiota and stimulated the growth of beneficial bacteria and the production of SCFA. The analysis of the results of studies involving commercial resistant starch types indicated that different types of commercial resistant starch were fermented by different bacterial populations, and different bacterial species were activated in microbiota modulation. The fact that there were differences between the resistant starch contents of commercial resistant starch types or that the source of resistant starch was different foods may have yielded these results. However, given the results of the studies, it is seen that commercially produced type II, type III, and type IV resistant starch may have the prebiotic capacity and potentially be as a candidate prebiotic component. In Table 5, the prebiotic capacities of commercially produced resistant starch types were presented.

Conclusion and recommendations

Various resistant starch types can be isolated from foods and are commercially available. In recent years, there has been an increasing interest in evaluating the prebiotic capacity of both commercially produced resistant starch types and resistant starches isolated from foods. The review of the literature data demonstrated that the prebiotic capacity of resistant starch isolated from foods is mostly investigated by in vitro studies, and the prebiotic capacity of commercially produced resistant starch types is investigated by both in vitro and in vivo studies. According to the analysis of the existing studies in detail, the results vary from one study to another, and there is no definite consensus on the use of resistant starch varieties as prebiotics. However, it is claimed that the number of studies yielding positive results is higher

and that resistant starch isolated from foods or produced commercially, especially type II, type III, and type IV resistant starch, can meet the necessary criteria as a prebiotic candidate. The fact that the results in the current literature differ from one study to another is attributed to methodological differences such as the resistant starch tested has different origins and percentages, and the microorganisms tested are different. In conclusion, the analysis of the studies included in this review suggests that of the commercial resistant starch types, type II, type III, and type IV resistant starch, and the resistant starch isolated from foods, type II and type III resistant starch have the prebiotic capacity and that they can be used as a prebiotic component.

Author contribution ED and TT conceived and designed the review. TT did the literature review and then classify the studies included in the review. ED and TT wrote the manuscript. All authors read and approved the manuscript.

Data Availability Datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request. The authors declare full data transparency.

Declarations

Ethics approval This article does not contain any studies on human participants or animals performed by any of the authors.

Conflict of interest The authors declare no competing interests.

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