

Properties of Potato Resistant Starch and Its Effect on the Growth of Probiotics

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Abstract: This study uses potato starch as raw material to prepare potato resistant starch (PRS₃) using a pressure heating dual enzyme method and purifies it. The physicochemical indicators such as swelling power, solubility, freeze-thaw stability, transparency, oil absorption, milk absorption, and water holding capacity of purified PRS₃ are measured. The growth and proliferation of probiotics (*Lactobacillus acidophilus*, *Lactobacillus bulgaricus*, *Bifidobacterium*, *Streptococcus thermophilus*, and *Lactobacillus paracasei*) under different carbon source concentrations of PRS₃ medium, soluble starch medium, and glucose medium, as well as their effects on the growth process are studied. The authors also discuss the effects of glucose medium and PRS₃ medium on salt and acid tolerance of probiotics. The results show that the freeze-thaw stability, solubility, and milk absorption capacity of PRS₃ are stronger than those of original potato starch, but its oil absorption, water holding capacity, swelling capacity, and transparency are weaker than those of original potato starch. When the carbon source concentration is 2.0%, the proliferative effect of PRS₃ on five bacteria is in descending order: *Lactobacillus acidophilus*, *Lactobacillus bulgaricus*, *Bifidobacterium*, *Streptococcus thermophilus*, and *Lactobacillus paracasei*. The ability of PRS₃ medium to promote the proliferation of probiotics is stronger than that of glucose medium and soluble starch medium. It has a protective effect on probiotics in low pH environments and can improve their resistance to bile salts.

Keywords: Potato resistant starch; Physical and chemical properties; Characteristics of prebiotics

1. Introduction

Resistant starch (RS), also known as enzymolysis-resistant starch or indigestible starch, is a novel dietary fiber component that cannot be broken down by host digestive enzymes in the small intestine but can undergo fermentation by certain microorganisms in the colon [1]. RS can be categorized into five types: RS1, physically encapsulated starch; RS2, native starch granules; RS3, retrograded starch; RS4, chemically modified starch; RS5, amylose-lipid complexes [2]. Potato resistant starch (PRS₃) is a type III resistant starch derived from potato starch, known for its role in promoting the proliferation of probiotics such as *Bifidobacterium*. It is commonly used in the food industry.

Currently, RS3 has garnered significant attention in the field of food research and production. Studies on producing RS3 from various foods, including bananas, rice, corn, sago, cassava, peas, wheat, potatoes, etc., have been conducted globally [3-10]. RS3 is characterized by its stable structure and excellent acid and heat resistance [11], making it heat-stable during cooking processes while retaining nutritional functionality. The structural features of RS3 are closely related to the physical state of its source starch, including the ratio of straight-chain to branched-chain starch, moisture and lipid content, degree of straight-chain starch polymerization, and properties of molecular helices [12]. Potato resistant starch, in particular, offers advantages such as large annual production capacity, simple production processes, low investment, and a wide range of industrial applications. It serves as a tasteless and odorless source of dietary fiber, contributing to the regulation of blood sugar, cholesterol, dynamic balance of gut microbiota, prevention of colon cancer and metabolic diseases, enhancement of immunity, and assistance in reducing obesity rates [13].

Therefore, this study investigates the properties of potato resistant starch and its impact on the growth of probiotics (*Lactobacillus acidophilus*, *Lactobacillus bulgaricus*, *Bifidobacterium bifidum*, *Streptococcus thermophilus*, *Lactobacillus paracasei*). The findings aim to provide data support for the further development of functional foods containing potato resistant starch.

2. Materials and Methods

2.1 Experimental Materials

Glucose:Guangzhou Jinyuan Chemical Co., Ltd.; Soluble starch: Henan Chen Nuo Biotechnology Co., Ltd.; *Lactobacillus bulgaricus*, *Streptococcus thermophilus*, *Animal bifidobacterium*, *Lactobacillus acidophilus*: Zhenjiang Tianyi Biotechnology Co., Ltd.; *Lactobacillus paracasei*: Shandong Zhongke Jiayi Biotechnology Engineering Co., Ltd.; MRS culture medium: Qingdao Haibo Biotechnology Co., Ltd.

2.2 Experimental Instruments and Equipment

BS2 23S Electronic Analytical Balance: Beijing Sartorius Instrument Co., Ltd.; UV-1200 UV/Visible Spectrophotometer: Shanghai Metash Instruments Co., Ltd.; 1260 Infinity pH Meter: Agilent Technologies (China) Co., Ltd.; D8023CTL-K4 High-pressure Steam Sterilizer: Guangdong Galanz Group Co., Ltd.; DK-98-IIA Electric Constant Temperature Water Bath: Tianjin Tesco Instrument Co., Ltd.; SW-CJ-2FD Aseptic Operation Table: Suzhou Purification Equipment Co., Ltd.; Bactron II Anaerobic Culture Chamber: SHELLAB, USA; KQ-250DE Digital Electric Incubator: Kunshan Ultrasonic Instrument Co., Ltd.

2.3 Experimental Methods

2.3.1 Preparation of PRS3

Potato resistant starch (PRS3) was prepared using a pressure heating dual enzyme method. Thirty grams of potato starch were weighed into a conical flask, and a starch suspension with a mass fraction of 15% was prepared. The flask was placed in a high-pressure steam sterilizer with a temperature set at 121°C for 20 minutes. After cooling to 60°C, the pH was adjusted to between 5.5 and 6.5. High-temperature-resistant α -amylase (6 U/g dry basis) was added, and enzymatic hydrolysis was carried out in a 95°C constant temperature water bath for 1 hour. After cooling to 60°C, pullulanase (12 U/g dry basis) was added, and the enzymatic hydrolysis was maintained at 60°C for 3 hours. After cooling to room temperature, the mixture was centrifuged at 4000 rpm for 10 minutes, the supernatant was removed, and the residue was aged in a 4°C refrigerator for 24 hours. After drying at 60°C for 36 hours, the product was ground and sieved through a 100-mesh sieve to obtain PRS3.

2.3.2 Purification of PRS3

A mass fraction 15% PRS3 suspension was prepared with an HCl-KCl buffer solution at pH 1.5. Excess pepsin was added, and the mixture was shaken in a 37°C water bath for 1 hour. After cooling to room temperature, the pH of the solution was adjusted to between 5.5 and 6.5, and high-temperature-resistant α -amylase was added for enzymatic hydrolysis at 95°C thermostatic water bath for 1 hour. After cooling to room temperature, the pH was adjusted to 4.0-4.5, and glucoamylase was added for enzymatic hydrolysis in a 60°C thermostatic water bath with shaking for 1 hour. The mixture was then centrifuged at 4000 rpm for 10 minutes, and the supernatant was washed 2-3 times with a 95% ethanol solution. After aging in a 4°C refrigerator for 24 hours and drying at 60°C for 36 hours, the product was ground and sieved through a 100-mesh sieve to obtain purified PRS3.

2.3.3 Determination of Physicochemical Properties of PRS3

Swelling Power and Solubility of PRS3: Twenty milliliters of a 1.5% (w/w) PRS3 suspension was weighed, and the empty tube weight was recorded as m_0 . The dry weight of starch was recorded as m_1 . The suspension was heated to 95°C, maintained for 10 minutes, cooled to room temperature, and then centrifuged at 4000 rpm for 20 minutes. The supernatant was poured out, and the weight of the precipitate and centrifuge tube was recorded as m_2 . After drying the supernatant, the weight was recorded as m_3 . The calculation formula is as follows:

$$\text{Solubility } S_0 = \frac{m_3}{m_1} \times 100\% \quad (1)$$

$$\text{Swelling capacity } W_0 = \frac{m_2 - m_0}{m_1 - m_3} \times 100\% \quad (2)$$

PRS3 Freeze-Thaw Stability: Twenty milliliters of a 1.5% (w/w) PRS3 suspension was weighed and recorded as m_1 . The empty tube weight was recorded as m_0 . The suspension was heated to 95 °C and maintained for 5 minutes, cooled to room temperature, then frozen at -20 °C for 24 hours in a freezer. After removal, it was thawed in a 30 °C water bath for 5 hours. After 5 cycles of freeze-thaw, the sample was centrifuged at 4000 rpm for 20 minutes. The supernatant was poured out, and the remaining mass was recorded as m_2 . The evaluation index is the water exhalation rate and the calculation formula is as follows:

$$\text{Water exhalation rate} = \frac{m_1 - m_2}{m_1 - m_0} \times 100\% \quad (3)$$

Transparency of PRS3: A suspension of PRS3 with a mass fraction of 1.5% (w/w) was prepared and placed in a 95°C water bath with stirring for 30 minutes. The mixture was then cooled to room temperature, and the light transmittance was measured at 620 nm using distilled water as a blank control.

Oil Absorption Capacity of PRS3: 1 g of PRS3 (m_1) was mixed with 6 mL of soybean oil in a centrifuge tube with continuous stirring. The centrifuge tube was then vortexed for 5 minutes, left to stand for 30 minutes to absorb the oil, and then centrifuged at 3000 rpm for 20 minutes. The supernatant was discarded, and the mass of the precipitate (m_2) was measured after drying. The oil absorption capacity was expressed as the weight gain and calculated using the formula:

$$\text{Oil Absorption Capacity} = \frac{m_2 - m_1}{m_1} \times 100\% \quad (4)$$

Milk Absorption Capacity of PRS3: The milk absorption capacity, quantified based on oil absorption capacity, involved adding 0.1 g of PRS3 (m_1) into 2 mL of raw milk. After drying, the mass of the precipitate (m_2) was measured. The calculation formula is:

$$\text{Milk Absorption Capacity} = \frac{m_2 - m_1}{m_1} \times 100\% \quad (5)$$

Water-holding Capacity of PRS3: 0.45 g of PRS3 (m_1) and 15 mL of distilled water (m_2) were added to a pre-weighed 50 mL centrifuge tube (m_0). The tube was placed in a 37°C water bath for 1 hour, centrifuged at 10,000 rpm for 10 minutes, and the supernatant was discarded. The centrifuge tube was then weighed (m_3), and the water-holding capacity was calculated.

$$\text{Water-holding Capacity} = \frac{m_3 - m_0}{m_1 + m_2} \times 100\% \quad (6)$$

2.3.4 Determination of Prebiotic properties of PRS3

2.3.4.1 Impact of PRS₃ on Probiotic Proliferation

PRS3 culture media with carbon source concentrations of 0.125%, 0.5%, 1%, 2%, 3%, 4%, soluble starch culture media, and glucose culture media, each 10 mL, were prepared and sealed in anaerobic tubes. After sterilization at 121°C for 20 minutes and cooling to room temperature, 0.25 mL of thrice-activated test bacterial strains were inoculated under aseptic conditions. The tubes were anaerobically cultured at 37°C for 48 hours, and the absorbance of the culture solution in each test tube was measured at 600 nm.

2.3.4.2 Influence of PRS₃ on the Growth Process of Probiotics

Analyzing the results from experiment 2.3.4.1, the carbon source concentration with the best proliferation effect for the test bacteria was selected from the three types of media. The experiment

was repeated following the procedure in 2.3.4.1, and cultures medium was prepared, sterilized, inoculated, and incubated at 37°C for 28 hours. At intervals of 2 hours, a small amount of culture fluid was taken, and the absorbance at 600 nm was measured. Cultures without added bacteria served as controls. The values for each group were recorded, and growth curves for each test strain were plotted using cultivation time and absorbance values as the X and Y axes, respectively.

2.3.4.3 Influence of PRS3 on Probiotic Salt and Acid Tolerance

The pH of glucose and PRS3 culture media was adjusted to 7.0. 0.5%, 1.0%, and 2.0% pig bile salts were separately added (sterilized at 121°C for 20 minutes) to the centrifuge tubes containing the test bacteria after centrifugation. The tubes were anaerobically cultured at 37°C, and viable strain counts were measured at 0 hours (B1) and 3 hours (B2).

Using a 37% hydrochloric acid solution, the pH of the experimental culture media was adjusted to 3.0, 2.0, and 1.5, sterilized at 121°C for 20 minutes, and added to the centrifuge tubes containing the test bacteria. The tubes were anaerobically cultured at 37°C, and viable bacterial counts were measured at 0 hours (B1) and 3 hours (B2). The formula for and viable strain counts were measured at 0 hours (B1) and 3 hours (B2).

Survival rate calculation is:

$$\text{Survival rate}\% = \frac{\lg B_1}{\lg B_2} \times 100\% \quad (7)$$

2.4 Data Analysis

Statistical analysis of the data was conducted using IBM SPSS 26, and all charts were generated using Origin2018.

3. Results and Analysis

3.1 Analysis of Physicochemical Properties of PRS3

Material	Original Potato Starch	PRS3 Sample
Purified RS3 Content/%	—	88.49±1.64
Particle Diameter/μm	20~80	10~30
Water Exhalation Rate/%	85.08±0.51	80.20±0.43
Solubility/%	18.49±0.86	36.95±2.34
Transparency/%	65.67±2.64	41.65±1.17
Oil Absorption Capacity/%	116.88±1.29	110.92±1.15
Milk Absorption Capacity/%	361.55±0.85	373.57±0.43
Swelling Capacity/(g/g)	16.95±2.34	10.21±1.51
Water-Holding Capacity/%	339.91±6.33	234.47±3.28

Table 1. Determination results of physicochemical properties of PRS3

According to Table 1, it can be observed that the water exhalation rate of PRS3 is lower than that of original potato starch, and the solubility of PRS3 is higher than that of original potato starch. The water exhalation rate and solubility can reflect the freeze-thaw stability of raw materials. A lower water exhalation rate and higher solubility indicate better freeze-thaw stability of the raw material. The study on the freeze-thaw stability of PRS3 can examine its application in yogurt products and its impact on the quality during low-temperature storage of yogurt.

The transparency of PRS3 is lower than that of original potato starch. Transparency affects the color of food, so when applying PRS3 to food, especially yogurt products, attention should be paid to the amount added to avoid adverse effects on the color of the food.

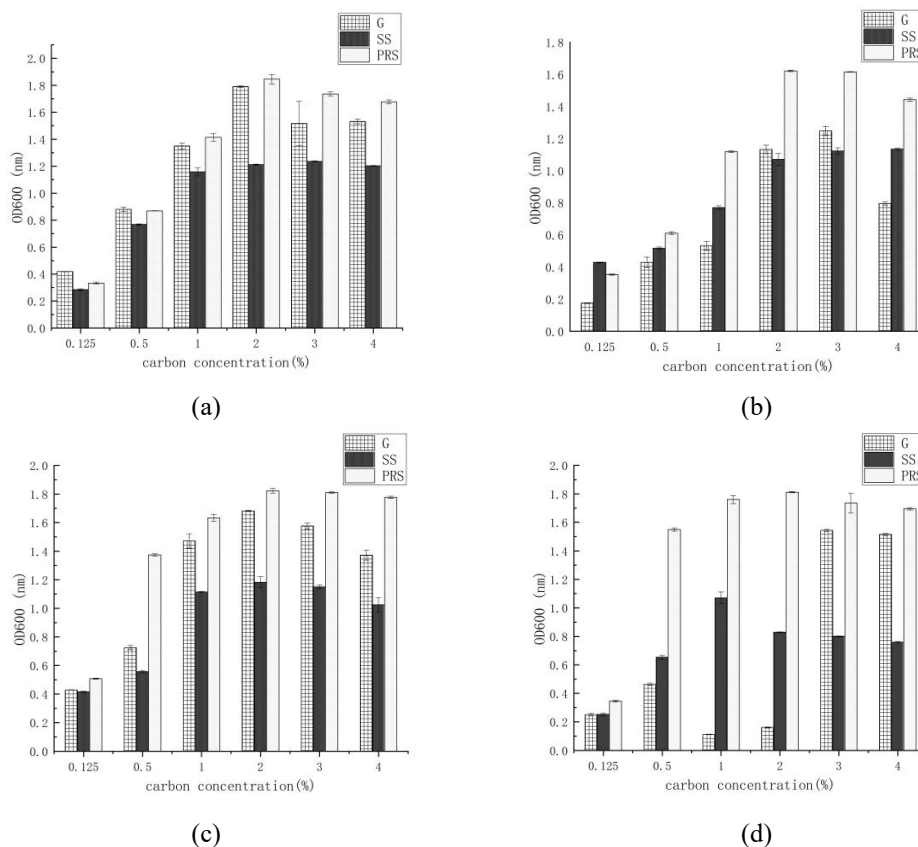
The oil absorption capacity of original potato starch is 89.55%, while the oil absorption capacity of PRS3 samples is 68.75%. During the preparation process, PRS3 undergoes high temperature and enzyme action, leading to an increase in RS3 content, rearrangement of starch structure, a decrease in starch particle diameter, and a reduction in oil absorption capacity. This suggests that its oil absorption capacity may be negatively correlated with particle size. The oil absorption capacity of starch depends on the binding degree of amylose-lipid complexes in the helical structure of starch [14]. At the same time, the porous structure of starch, under the action of capillary force, encloses the oil, but high temperature and enzyme action cause the straight-chain starch to rearrange into compact double-helix crystals, reducing porosity, decreasing hydrophobic proteins [15], and limiting oil absorption.

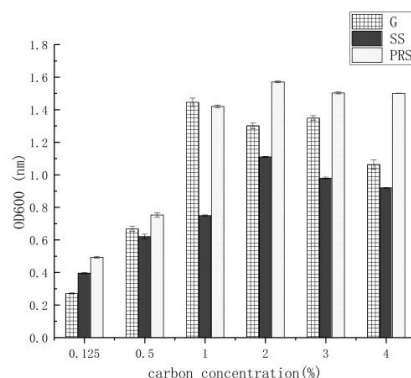
The milk absorption capacity of PRS3 is significantly higher than that of original potato starch ($p < 0.05$). The reason for the increased milk absorption capacity of PRS3 may be that the high temperature and pressure, along with enzyme action, induce the debranching of branched starch, leading to an increase in the level of amylose. Amylose can form complexes with casein in milk [16], resulting in a significant binding of amylose with casein.

The water-holding capacity and swelling capacity of PRS3 are significantly lower than that of original potato starch ($p < 0.05$). This is because the crystalline structure content of branched starch in original potato starch is high, allowing it to absorb moisture for uniform consistency. Brown [17] suggested that resistant starch particles, due to the high content of straight-chain starch, cannot fully gelatinize even at the boiling point of water. Therefore, the interaction between the produced PRS3 samples and water molecules is minimal.

3.2 Results Analysis of Prebiotic Properties of PRS3

3.2.1 Analysis of the Effect of PRS3 Concentration on Probiotic Proliferation





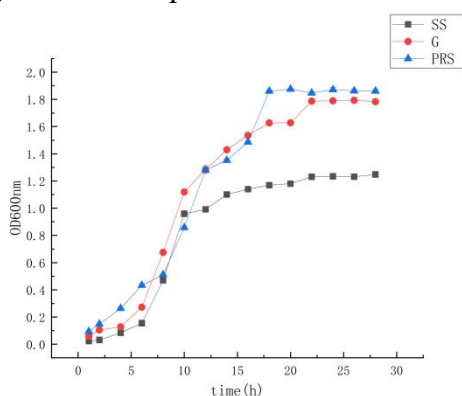
(c)

Fig. 1. Effect of carbon source concentration on the number of probiotics (OD600nm)

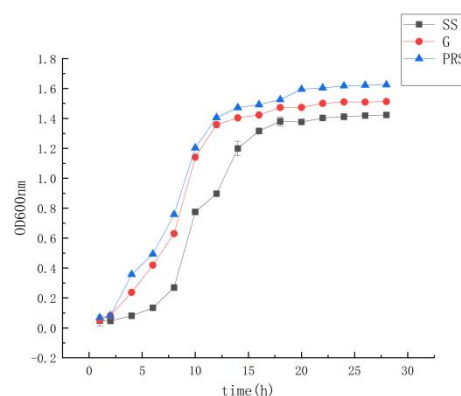
Note: a. *Lactobacillus bulgaricus*; b. *Thermophilic Streptococcus*; c. *Lactobacillus acidophilus*; d. *Lactobacillus paracasei*; e. *Animal Bifidobacterium*

The type and concentration of carbon sources can influence the growth and proliferation of probiotic bacteria. The proliferation effects of five tested strains in culture media with different carbon source concentrations are illustrated in Fig. 1. Across all carbon source concentrations, the OD600nm values in media containing PRS3 are significantly higher compared to those with G (glucose) or SS (soluble starch) ($p < 0.05$). When the carbon source concentration is 2%, the OD600nm values for all carbon source media reach their maximum. Based on the OD600nm values, PRS3 exhibits varying degrees of proliferation effects on the five tested strains. When the carbon source concentration is 2%, the order of proliferation effects of PRS3 on the five strains is as follows: *Lactobacillus acidophilus* > *Lactobacillus bulgaricus* > *Animal Bifidobacterium* > *Streptococcus thermophilus* > *Lactobacillus paracasei*. Compared to G and SS, PRS3 shows varying degrees of promotion for all tested strains, which may be related to the relative crystallinity of PRS3 starch chains and the surface morphology of starch particles. Excess carbon source concentration in the culture medium may lead to carbon and nitrogen source diversion. Studies have indicated that carbon and nitrogen source diversion could pose a threat to the growth and proliferation of bacteria[18], potentially being detrimental to bacterial growth. Furthermore, high concentrations of carbon sources in the culture medium can have a negative impact on the enzyme systems and transport capabilities of bacteria.

3.2.2 Analysis of the Impact of PRS3 on the Growth Process of Probiotics



(a)



(b)

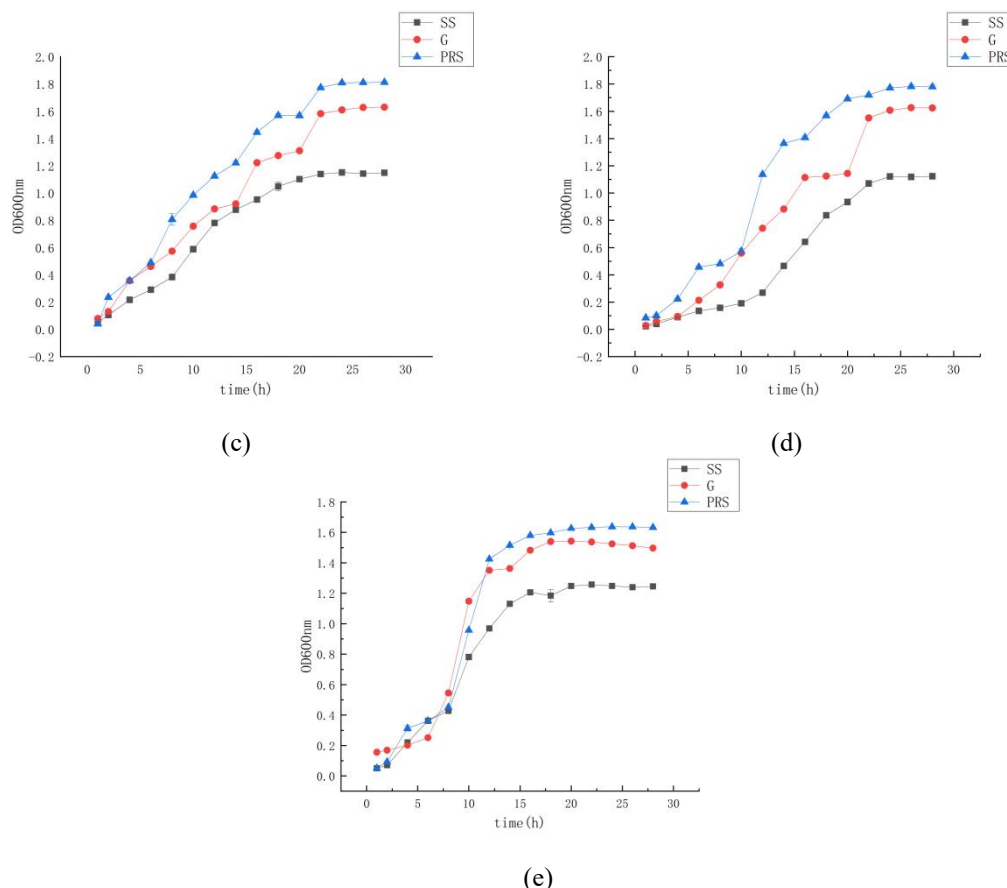


Fig. 2. Effect of PRS3 on the number of bacteria (OD600nm) during the growth of probiotics

Note: a. *Lactobacillus bulgaricus*; b. *Thermophilic Streptococcus*; c. *Lactobacillus acidophilus*; d. *Lactobacillus paracasei*; e. *Animal Bifidobacterium*

From Fig. 2, it is evident that in culture media containing different carbon sources, *Lactobacillus bulgaricus* and *Animal bifidobacterium* exhibit similar overall growth trends, indicating strong adaptability. During the initial 4 hours, there is a lag phase in their growth, followed by exponential growth from 4 to 16 hours, and a slower growth phase from 16 to 18 hours before entering a stable growth phase after 18 hours. In contrast, *Lactobacillus acidophilus* and *Lactobacillus paracasei* have a lag phase of 6 hours, during which the bacterial concentration changes minimally. From 6 to 18 hours, they undergo exponential growth, and after 18 hours, they enter a stable phase. *Lactobacillus acidophilus* and *Lactobacillus paracasei* exhibit higher growth rates in the PRS3 culture medium compared to the G and SS groups, with higher bacterial concentrations. In summary, this indicates that the ability of PRS3 culture medium to promote the proliferation of probiotic bacteria is stronger than that of G and SS.

3.2.3 Impact of PRS3 on the Acid and Salt Tolerance of Probiotic Bacteria

Table 2. Tolerance of probiotics in different media with low pH (survival rate%)

pH	3.0	2.0	1.5
G + <i>Lactobacillus bulgaricus</i>	65.85±0.69	58.66±0.21	—
PRS3 + <i>Lactobacillus bulgaricus</i>	72.28±0.28	68.97±0.28	—
G + <i>Streptococcus thermophilus</i>	58.23±0.08	45.62±1.99	—
PRS3 + <i>Streptococcus thermophilus</i>	59.77±0.47	55.92±0.19	—
G + <i>Lactobacillus paracasei</i>	64.27±1.75	61.46±0.10	—

PRS3 + <i>Lactobacillus paracasei</i>	75.29±0.39	69.98±0.19	—
G + <i>Lactobacillus acidophilus</i>	75.76±0.11	69.66±0.32	—
PRS3 + <i>Lactobacillus acidophilus</i>	75.76±0.03	73.52±0.26	—
G + <i>Animal bifidobacterium</i>	78.69±0.14	74.68±0.29	—
PRS3 + <i>Animal bifidobacterium</i>	81.46±0.10	79.98±0.10	—

Ensuring the safe arrival of probiotics to specific locations where they can exert their functions is crucial. Probiotics need to possess robust survival capabilities under conditions of high salt concentration and low pH, coupled with sufficient activity. Additionally, a protective layer is required to assist in resisting adverse environments and enabling them to function in the intestinal tract. The pH of human gastric fluid typically ranges between 1.5 and 3.0. In this study, culture media with pH values of 1.5, 2.0, and 3.0 were used to evaluate the ability of PRS3 to improve the acid resistance of the tested bacteria. From Table 2, it is evident that the test strains exhibited robust growth at pH 3.0, with significantly higher survival rates in the PRS3 group compared to the G group ($p < 0.05$). Moreover, the highest survival rate of *Lactobacillus bulgaricus* in PRS3 group was 72.28%. As the pH dropped to 2.0, the activity of the test strains was affected, and their viability significantly decreased. However, the survival rate in the PRS3 group remained higher than that in the G group, exceeding 60%, indicating that PRS3 enhances the acid tolerance of the test strains under low pH conditions. At pH 1.5, no viable strains were detected in either group, indicating a strong inhibitory effect of excessively low pH on the test strains. In summary, PRS3 demonstrates superior protective effects on the test strains under low pH conditions compared to G. This may be attributed to the rough surface of PRS3, providing more spaces that act as a protective barrier for the test strains. This finding is consistent with Zeng's results that the grooved surface of resistant starch is *Bifidobacterium* protected from adverse conditions[19].

Table 3. Tolerance of probiotics in different media containing bile salts (survival rate%)

Bile Salt Concentration	0.5%	1.0%	2.0%
G+ <i>Lactobacillus bulgaricus</i>	86.31±0.82	55.72±1.55	20.84±0.56
PRS3+ <i>Lactobacillus bulgaricus</i>	91.92±0.38	65.08±1.18	38.81±0.91
G+ <i>Thermophilic Streptococcus</i>	78.07±1.56	45.82±1.21	22.27±0.24
PRS3+ <i>Thermophilic Streptococcus</i>	84.77±0.53	71.39±0.44	22.52±0.44
G+ <i>Lactobacillus acidophilus</i>	86.47±0.43	43.64±2.00	33.48±0.60
PRS3+ <i>Lactobacillus acidophilus</i>	90.83±0.45	68.07±0.55	38.31±0.66
G+ <i>Bifidobacterium</i>	80.02±0.18	75.58±0.32	44.93±0.08
PRS3+ <i>Bifidobacterium</i>	83.02±0.29	80.58±0.33	52.41±0.41
G+ <i>Lactobacillus paracasei</i>	80.32±0.61	51.25±0.58	34.01±0.42
PRS3+ <i>Lactobacillus paracasei</i>	83.78±2.60	53.44±0.50	36.96±0.52

From Table 3, it is evident that the survival rate of the tested strains in the culture medium is significantly higher than that in the G group ($p < 0.05$). When the bile salt concentration is 0.5%, the tested strains survival rate remains above 80%, and at a bile salt concentration of 2.0%, the tested strains survival rate is maintained at around 40%. This indicates that PRS3 can enhance the resistance of the tested strains to bile salts. The reason may be that after high temperature and

enzyme action, the original potato starch changes from oval to massive, and the surface is rough into fish-scale-like, creates conditions for bacterial adhesion, protecting them from the erosion of bile salts [20].

4. Conclusion

In comparison with original potato starch, PRS3 exhibits superior freeze-thaw stability, solubility, and milk absorption capacity but inferior oil absorption, water-holding capacity, swelling capacity, and transparency. PRS3 demonstrates varying degrees of proliferation effects on five tested strains. When the carbon source concentration is 2.0%, the order of proliferation effects of PRS3 on the five strains is as follows: *Lactobacillus acidophilus* > *Lactobacillus bulgaricus* > *Bifidobacterium* > *Thermophilic Streptococcus* > *Lactobacillus paracasei*. The ability of PRS3 culture medium to promote the proliferation of probiotic bacteria is stronger than that of G (glucose) and SS (soluble starch) culture media, providing protection for the tested strains in low pH environments and enhancing resistance to bile salts. This study provides valuable data support for understanding the growth-promoting effects of potato resistant starch (PRS3) on probiotic bacteria and evaluating its practical application value. It offers new insights into probiotic protection, but further research is needed to explore the impact of potato resistant starch on gut microbiota when added to food.

Acknowledgments

This paper is supported by the following fund projects: Heilongjiang Natural Science Foundation Project (LH2021C077) and Harbin Science and Technology Plan self-financing Project (ZC2022ZJ020005).

References

- [1] Dupuis J H, Liu Q, Yada R Y. Methodologies for increasing the resistant starch content of food starches: a review[J]. *Comprehensive Reviews in Food Science & Food Safety*, 2015, 13(6): 1219-1234.
- [2] Recife A, Meneguín A B, Cury B, et al. Evaluation of retrograded starch as excipient for controlled release matrix tablets[J]. *Journal of Drug Delivery Science and Technology*, 2017, 40(8): 83-94.
- [3] Huang Ming, Huang Hongming, Xiong Wei, et al. Research Progress on Resistant Starch in Bananas[J]. *Light Industry Science and Technology*, 2020, 36(9): 17-19+51.
- [4] Han Zhifei, Liu Huiping, Si Kai, et al. Study on the preparation of resistant starch from rice by wet-heat method[J]. *Food Safety Guide*, 2021(3): 130-131.
- [5] Khan A, Siddiqui S, Rahman U U, et al. Physicochemical properties of enzymatically prepared resistant starch from maize flour and its use in cookies formulation[J]. *International Journal of Food Properties*, 2020, 23(1): 549-569.
- [6] Chang Lei, Wang Jieru, Yang Min, et al. Research on quality characteristics of sago[J]. *Food and Machinery*, 2021, 37(2): 28-33.
- [7] Wu Heng. Research on the different preparation methods of resistant starch and its influential factors of formation[D]. Nanning, Guangxi University, 2014.
- [8] Yin Lebin, He Ping, Liu Yali, et al. Optimization of preparation process and physicochemical properties of resistant starch from peas[J]. *China Brewing*, 2022, 41(2): 198-203.
- [9] Ortega A. Physicochemical characterization of resistant starch type-III (RS3) obtained by autoclaving malanga (*Xanthosoma sagittifolium*) flour and corn starch[J]. *Molecules*, 2021, 26(13): 4006.
- [10] Li W, Zhou Z, Fan S, et al. Formation of type 3 resistant starch from mechanical activation-damaged high-amylose maize starch by a high-solid method[J]. *Food Chemistry*, 2021, 363(3): 130344.
- [11] Zeng Chao, Liu Yilin, Xiao Meifang, et al. Research progress on RS3-type resistant starch[J]. *Science and Technology of Food Industry*, 2020, 41(7): 338-344.

- [12] Ma Z, Hu X, Boye J I. Research advances on the formation mechanism of resistant starch type III: a review[J]. *Critical Reviews in Food Science and Nutrition*, 2020, 60(2): 276-297.
- [13] Liang Dan. Study on the mechanism of potato resistant starch inhibits obesity by modulating the composition of intestinal microbiota[D]. Beijing, Chinese Academy of Agricultural Sciences, 2021.
- [14] Porras D P N, Suárez M G, Umaña J. H. Optimization of Physical, optical and barrier properties of films made from cassava starch and rosemary oil[J]. *Journal of Polymers & the Environment*, 2019, 27(1): 127-140.
- [15] Jones M G, Biol. M I, Ph. D, et al. Milk protein-amylose interaction in solution[J]. *Starch*, 2010, 28(10): 338-341.
- [16] Ian Brown, M Sc. Complex carbohydrates and resistant starch[J]. *Nutrition Reviews*, 1996, 54(11): 115-119.
- [17] Li D, Jin M K, Jin Z, et al. Prebiotic effectiveness of inulin extracted from edible burdock[J]. *Anaerobe*, 2008, 14(1): 29-34.
- [18] Liu Shuxing, Hou Min, Xu Chen, et al. Study on the proliferation of probiotics by resistant starch[J]. *Food Science and Technology*, 2019, 44(1): 14-20.
- [19] Zeng S, Wu X, Lin S, et al. Structural characteristics and physicochemical properties of lotus seed resistant starch prepared by different methods[J]. *Food Chemistry*, 2015, 186(1): 213-222.
- [20] Chen B, Zeng H, Yi Z, et al. Structural characteristics and prebiotic effects of Semen coicis resistant starches (type 3) prepared by different methods[J]. *International journal of biological macromolecules*, 2017, 105(1): 671-679.