

Short Communication

Sources and intake of resistant starch in the Chinese diet

Liyong Chen MD¹, Ruiping Liu MD², Chengyong Qin MD¹, Yan Meng MPH³, Jie Zhang MPH¹, Yun Wang MPH³, Guifa Xu MD³

¹Nutritional department of Provincial hospital affiliated to Shandong University, Jinan, China

²Nutritional department of Xian Children's Hospital, Xian, China

³Institute of Nutrition and Food Hygiene of Shandong University, Jinan, China

Resistant starch (RS) escapes digestion in the small intestine and may ferment in the large intestine. The purpose of this study was to determine the resistant starch content in typical starchy foods and to estimate the daily resistant starch intake and identify key sources of dietary resistant starch in the Chinese diets. The resistant starch contents of 121 foods were determined using a method that mimicked gastrointestinal conditions. Tubers and legumes had high resistant starch contents. Rough food processing retained large amounts of resistant starch. In general, the content of RS decreased when foods were cooked. Deep fried and roasted foods had higher levels of resistant starch than braised foods. The average resistant starch intake in the Chinese population was estimated to be 14.9 g per day based on a dietary survey. The main resistant starch sources in the Chinese diet were cereal and tuber products. Based on dietary habits, however, the resistant starch intake varies considerably among individuals.

Key Words: content, dietary survey, intake, resistant starch, source

INTRODUCTION

For nutritional purposes, starch in foods may be classified into three types according to *in vitro* digestibility: rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS).¹ RS is defined as "the sum of starch and the products of starch degradation not absorbed in the small intestine of healthy individuals".² In the gastrointestinal tract, the rapidly and slowly digestible fractions are digested and absorbed in the small intestine, generally within 120 min of consumption of foods, whereas RS is fermented in the colon.¹ By the standard American Association of Cereal Chemists method for determining dietary fiber (DF), RS is insoluble and possesses physiologic properties similar to those of DF. Nutritional studies have shown that RS improves lipid and cholesterol metabolism, increases fecal bulk, reduces the risk of ulcerative colitis, colorectal cancer, coronary heart disease, constipation, and Type II diabetes and binds toxins, bile acids, and carcinogens.³⁻⁵

The nature of RS in foods is variable and is classified on the basis of its botanical source and processing. It occurs as physically inaccessible starch (RS1), resistant starch granules (RS2), retrograded starch (RS3), and chemically modified starch (RS4). The RS1 fraction is physically inaccessible to digestion as it is entrapped in a non-digestible matrix, whereas RS2 is native dehydrated granular starch packed in a compact molecular structure that limits the accessibility of amylases. The RS1 and RS2 fractions occur in whole cereal grains and root crops, respectively, and have significant nutritional value even after cooking and processing. The content of RS1 and RS2 fractions represent most of the RS in a typical diet.

After the processing of amylose polymers, gelatinization, and recrystallisation, the RS3 fraction is formed. This fraction is enzyme-resistant; the starches adopt a double helix structure stabilized by hydrogen bonds, which is characterized by a high thermal stability.^{1,3,6} RS4 is formed by chemical modification of starch.

Legumes, potatoes, banana and cereals are typical sources of starch and have been shown to contain various amounts of RS.^{7,8} Several factors can influence RS quantities, including botanical origin, starch nature (amylose/amylopectin ratio, interaction between starch/nutrients), food processing (starch gelatinization degree, particle size, cellular structure, starch granules variation) and the presence of other components (lipids, protein, dietary fiber, antinutrients, and organic acids).⁹

Obesity, cardiovascular disease, diabetes, and cancer have recently become major threats to human health in many nations at least in part due to changes in eating and drinking habits. Although the etiology is multi-factorial, diet has been identified as the most important environmental risk factor for development of these diseases. Thus, dietary modification, like increases in dietary fiber intake, could be a cost-effective way to reduce prevalence of these conditions. RS should be taken into account when the optimum level of daily dietary fiber is determined.

Corresponding Author: Prof Guifa Xu, Institute of Nutrition and Food Hygiene of Shandong University, Jinan, China.

Tel: 86 0531 88382135; Fax: 86 0531 88382208

Email: yyxu@sdu.edu.cn

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Thus, it becomes important to determine the RS content of foods. The true value of RS can be derived only from that found in the contents of the terminal ileum. However, to date, only two methods have been utilized for *in vivo* measurement of RS in the terminal ileum. One method requires individuals to be subjected to an ileostomy¹⁰⁻¹² and the other requires oral or nasal intubation of the ileum through the gut.^{13,14} These methods both have limitations. In the first approach, the ileostomy subjects analyzed usually have had a history of gastrointestinal disease and their intestinal function might be modified by the ileostomy. Moreover, the intestinal flora of ileostomy subjects may be quite different from that of healthy subjects. In the oral or nasal intubation studies, accurate physiological measurement may be prevented by the existence of a tube in the small intestine where foodstuffs are digested and absorbed. Clearly, a suitable methodology to measure RS needs to be developed so that the RS content of foods can be estimated.

Some data concerning RS content in common food products is available. The RS intakes in 10 different European countries have been evaluated from national consumption statistics.¹⁵ According to these calculations, the RS intake varied from 3.2 g to 5.7 g/day depending on country. Brighenti et al.¹⁶ estimated that the intake of RS was 8.5 g/day in the Italian diet based on representative analysis of the main sources of starch intake. Silvester et al.¹⁰ showed that RS intakes varied from 0.4 g to 34.8 g/day, depending on dietary starch content and type. In 2008, Murphy et al.¹⁷ reported that RS intake was 3g-8 g/day for Americans. A survey by Muir et al. estimated that the content of total starch and RS of the low-income Chinese diet is 392 g/day and 17.6 g/day, respectively.¹⁸

Using an analytical method that mimics gastrointestinal conditions *in vitro*, the RS contents of typical starchy foods common in the Chinese diet were determined. The contents of total starch (TS) were also evaluated. In addition, the daily RS intake among the Chinese was estimated based on a dietary survey.

MATERIALS AND METHODS

Sample preparation

Seven kinds of food samples (cereals, tubers, legumes, starches, vegetables, nuts and seeds, fruits) consumed in a typical Chinese diet were included in the study. Forty-nine raw foods (Table 1) and 72 cooked food products (Table 2) were tested. These samples were obtained from local farm product markets or supermarkets.

The *in vitro* model mimics gastrointestinal enzyme digestion.^{19,20} Mechanical agitation was performed with glass pearls (to mimic chewing), the samples were then blended and two 0.1-0.2 g samples were taken. The samples were weighed (accurately to 0.0001 g) and subjected to enzymolysis to determine the content of TS and RS. Foods were prepared according to typical Chinese cooking methods and were analyzed immediately after cooling to room temperature. Samples with more than 10% fat content were defatted with absolute ether prior to the analysis.

Total starch analysis.

Total starch (TS) content was determined according to the method of Goñi et al.¹⁸ Samples (50 mg) were suspended in 2 M KOH to disperse starch and shaken at room temperature for 30 min. The samples were incubated (60°C, 45 min) at pH 5.0 in a 1 mL solution of amyloglucosidase (300 U/mL, Sigma 10113) to hydrolyze starch. The free glucose was determined using the glucose oxidase method.⁷ Total starch was calculated as glucose (g) × 0.9(g/100g). Corn starch was used as reference standard. All chemicals used were at least of analytical grade.

Resistant starch analysis

The RS content was analyzed using the procedure described by Goñi et al.⁷ and Åkerberg et al.¹⁹ Briefly, the samples were incubated (40°C, 60 min, pH 2.0) in a 1 mL solution of pepsin (10 mg/mL, Sigma P-7012) to remove protein and then 0.1 mL of α -amylase (40 mg/mL, Sigma A-3176) was added and the sample was incubated at 37°C for 16 h at pH 5.0 to hydrolyze digestible starch. Next, the residue was treated with 2 M KOH to solubilize RS and was then incubated (60°C, 45 min, pH 5.0) with 140 U/mL amyloglucosidase (Sigma 10113) in 80 mL to hydrolyze the solubilized resistant starch. Finally, glucose was determined as described above.

Dietary survey

Dietary surveys were completed by 6382 men and women aged 18 to 70 from cities and countryside areas of China. This study was approved by the Ethics Committee of Shandong University (China). A food frequency questionnaire was administered to each subject. Information was obtained on the frequency that certain foods and liquids were consumed (daily, weekly, monthly, yearly, occasionally, or never) and the portion size (small, medium, and large). Portion sizes were estimated using common household bowls, dishes, spoons, cups, and glasses.

All subjects were asked to complete a dietary record for 7 consecutive days of food items and liquids consumed. Each subject was issued appropriate dietary intake recording sheets. At the beginning of the 7-day period, each subject was given detailed instructions on how to estimate the amount of each food item consumed. The procedure was then repeated by the subjects in the presence of the investigator to ensure competence. Subjects were visited on at least four different occasions during the 7 day period. On the eighth day, the subjects were visited to check the dietary intake recording sheets for completeness and accuracy. At that time, each subject was asked to provide a complete description of the methods of preparation, cooking, and recipes used for composite dishes.

Estimation of resistant starch intake

Based on the RS values measured and on food consumption data (g/subject/day) calculated from the dietary survey, RS intake was estimated for each individual. In addition, the main sources of RS in foods were also determined.

RESULTS AND DISCUSSION

Total starch and resistant starch in raw foods

In Table 1, the total starch (TS) and resistant starch (RS) are listed for the 49 raw food materials tested. The major-

Table 1. Total starch and resistant starch in raw food materials[†]

| Food | TS [‡] (g/100 g esculent) | RS [§] (g/100 g TS) |
|---|------------------------------------|------------------------------|
| Cereals | | |
| 1. Wheat flour, refined, special grade 1 | 87.0±4.74 | 4.37±0.32 |
| 2. Wheat kernel | 77.0±3.32 | 25.6±0.68 |
| 3. Glutinous rice | 80.1±3.11 | 20.8±0.76 |
| 4. Corn | 84.6±2.39 | 16.0±0.83 |
| 5. Round grained rice | 84.4±14.4 | 15.9±1.82 |
| 6. Long grained rice, fragrant | 84.8±1.22 | 10.3±1.12 |
| 7. Foxtail millet, hulled | 77.9±0.33 | 17.6±0.99 |
| 8. Long grained rice, purple | 80.0±3.76 | 19.3±5.81 |
| 9. Broomcorn millet, hulled, yellow | 77.0±2.53 | 18.1±1.62 |
| 10. Buckwheat, hulled | 76.0±5.81 | 23.6±7.01 |
| 11. Sorghum | 86.6±2.89 | 43.7±6.83 |
| 12. Adlay | 68.5±1.23 | 10.7±1.77 |
| 13. Oat flour | 85.6±6.03 | 1.82±0.63 |
| Dried legumes | | |
| 14. Soybean | 30.0±0.84 | 11.4±1.36 |
| 15. Kidney bean, red | 43.9±8.21 | 32.3±4.03 |
| 16. Red bean | 47.7±9.38 | 17.3±1.28 |
| 17. Black soybean | 19.9±2.83 | 26.7±0.39 |
| 18. Mung bean | 56.7±2.91 | 29.4±2.23 |
| 19. Garden pea | 68.2±6.99 | 21.3±4.86 |
| 20. Common cowpea | 44.1±4.11 | 28.7±4.54 |
| 21. Kidney bean, purple | 66.0±3.37 | 27.1±4.73 |
| 22. Soybean stick, dried, skimmed from soybean milk | 21.8±3.20 | 20.4±2.53 |
| Tubers | | |
| 23. Potato (preserved) | 19.5±3.16 | 12.7±1.91 |
| 24. Potato (fresh) | 15.0±0.63 | 72.0±5.82 |
| 25. Sweet potato, white flesh | 27.3±0.24 | 30.1±2.14 |
| 26. Big taro | 18.5±0.84 | 44.1±4.85 |
| 27. Taro | 18.8±0.89 | 27.5±2.65 |
| 28. Yam | 31.1±1.48 | 27.6±2.43 |
| Starches | | |
| 29. Corn starch | 96.8±1.58 | 7.83±2.02 |
| 30. Potato starch | 98.9±4.84 | 79.3±9.06 |
| 31. Sweet potato starch | 92.6±0.90 | 28.9±11.63 |
| 32. Cassava starch | 88.8±4.20 | 80.8±14.82 |
| Vegetables | | |
| 33. Water caltrop | 29.0±2.65 | 41.5±9.72 |
| 34. Water caltrop, dried | 82.4±1.81 | 36.8±3.33 |
| 35. Water chestnut | 9.01±0.84 | 8.05±0.78 |
| 36. Lotus root | 13.7±1.71 | 2.10±0.45 |
| 37. Water bamboo | 1.66±0.09 | 17.7±0.79 |
| 38. Pumpkin | 5.63±0.12 | 37.1±2.42 |
| 39. Chinese wax gourd | 2.94±0.30 | 0.00±0.00 |
| 40. Lily, dried | 73.1±3.75 | 10.5±0.09 |
| 41. Garlic bulb | 1.36±0.26 | 0.00±0.00 |
| 42. Silverweed cinquefoil | 58.9±3.23 | 23.2±3.15 |
| 43. Kidney bean, green, with pod | 1.56±0.04 | 6.93±2.87 |
| 44. Hyacinth bean, green, with pod | 1.60±0.05 | 6.15±0.35 |
| 45. Pale green soybean, without seed coat | 27.0±0.10 | 14.9±1.85 |
| Fruits | | |
| 46. Green banana | 18.7±2.15 | 38.3±3.10 |
| 47. Ripe banana | 16.7±0.61 | 4.85±0.40 |
| Nut and seed | | |
| 48. Cashew nuts | 49.8±4.72 | 12.9±0.19 |
| 49. Lotus seed, dried | 72.5±2.56 | 19.7±2.02 |

[†] Values are means ± SD of five replicates

[‡] TS, total starch

[§] RS, resistant starch

ity of TS figures are in good agreement with carbohydrate data from a previous analysis.²⁰

Cereals

In the thirteen cereals (two flour, eleven grain) analyzed, the RS contents were lower in cereal flour than in grain.

RS contents were 1.82% (on a total starch basis) in oat flour, and 4.37% in refined wheat flour. However, the RS levels in cereal grains varied from 10.3% to 42.7%. The higher RS levels in cereal grain than in flour were probably due to the fact that a part of the starch remained encapsulated in the grain structure. Digestive amylases may

Table 2. Total starch and resistant starch in cooked food products[†]

| Food product and description | Serving size (g) | TS [‡] (g/100 g esculent) | RS [§] (g/100 g TS) | RS (g/100g esculent) |
|--|------------------|------------------------------------|------------------------------|----------------------|
| Cereals | | | | |
| 1. Wheat bun, leavened, steamed | 20 g | 59.7±1.98 | 3.71±0.62 | 2.21±0.56 |
| 2. Wheat bun, leavened, baked | 20 g | 79.2±4.70 | 2.38±0.47 | 1.89±0.48 |
| 3. Wheat noodle | 25 g | 27.7±1.61 | 3.51±0.86 | 0.97±0.25 |
| 4. Wheat dough stick, deep-fried | 30 g | 76.8±1.47 | 4.28±0.29 | 3.29±0.86 |
| 5. Wheat pancake, deep-fried | 30 g | 43.8±2.81 | 6.47±0.42 | 2.83±0.45 |
| 6. Wheat kernel porridge | 125 g | 21.3±5.54 | 12.8±0.31 | 2.72±0.12 |
| 7. Round grained rice, steamed | 50 g | 34.2±3.16 | 3.60±0.52 | 1.23±0.08 |
| 8. Long grained rice, fragrant, steamed | 50 g | 44.3±1.08 | 4.21±0.71 | 1.87±0.15 |
| 9. Glutinous rice lumps, steamed | 50 g | 40.7±7.23 | 2.68±0.06 | 1.09±0.06 |
| 10. Round grained rice porridge | 125 g | 19.5±2.48 | 5.93±1.15 | 1.16±0.10 |
| 11. Corn bun, leavened, steamed | 60 g | 59.2±7.87 | 10.3±2.74 | 6.08±1.02 |
| 12. Corn flour paste, yellow | 125 g | 17.0±1.07 | 5.08±2.74 | 0.86±0.08 |
| 13. Corn flake porridge, instant | 125 g | 18.1±0.59 | 7.45±1.95 | 1.35±0.06 |
| 14. Corn grits porridge, yellow | 125 g | 12.0±0.43 | 7.10±0.71 | 0.85±0.12 |
| 15. Corn, yellow, fresh, steamed | 50 g | 36.4±3.22 | 2.65±0.13 | 0.96±0.07 |
| 16. Sticking corn, steamed | 50 g | 51.7±6.09 | 7.47±0.46 | 3.86±0.11 |
| 17. Foxtail millet porridge | 125 g | 37.1±2.69 | 7.39±0.80 | 2.74±0.10 |
| 18. Foxtail millet pancake, unleavened | 30 g | 95.3±2.36 | 5.16±1.87 | 4.92±0.14 |
| 19. Long grained rice porridge, purple | 125 g | 22.5±0.95 | 13.6±4.21 | 3.06±0.12 |
| 20. Sorghum porridge | 125 g | 27.3±2.66 | 9.83±0.88 | 2.68±0.07 |
| 21. Broomcorn millet flour paste | 20 g | 14.6±0.36 | 2.59±0.13 | 0.38±0.04 |
| 22. Buckwheat porridge | 125 g | 7.99±0.62 | 8.32±1.43 | 0.66±0.02 |
| Ethnic food, fast food and cakes made mainly with cereals | | | | |
| 23. Wheat noodle, instant | 30 g | 74.0±6.75 | 4.11±0.89 | 3.04±0.66 |
| 24. Bread | 20 g | 80.0±5.89 | 6.03±0.31 | 4.82±0.55 |
| 25. Biscuit | 20 g | 93.0±2.15 | 6.06±0.66 | 5.63±0.49 |
| 26. Fried dough twisted, crispy | 30 g | 72.5±7.44 | 7.98±0.91 | 5.79±0.78 |
| 27. Cake, with egg and baking powder, baked | 20 g | 33.9±3.86 | 12.0±0.20 | 4.05±0.86 |
| 28. Walnut cookie, with walnuts and vegetable oil, baked | 20 g | 70.5±8.17 | 11.8±0.26 | 8.29±0.96 |
| 29. Wheat Starch jelly sheet, steamed, cooled | 20 g | 27.3±2.90 | 16.3±1.73 | 4.47±0.75 |
| 30. Rice noodle | 30 g | 19.5±3.01 | 9.87±0.17 | 1.92±0.24 |
| 31. Oatmeal flake | 20 g | 75.6±9.49 | 4.76±0.50 | 3.60±0.68 |
| Legumes | | | | |
| 32. Red bean porridge | 125 g | 30.3±5.24 | 14.7±0.72 | 4.45±0.92 |
| 33. Red bean paste | 20 g | 22.8±1.18 | 14.3±0.03 | 3.26±0.68 |
| 34. Soybean, boiled | 20 g | 10.3±2.31 | 12.3±1.10 | 1.27±0.04 |
| 35. Garden pea, boiled | 70 g | 27.2±1.03 | 14.1±3.15 | 3.84±0.42 |
| 36. Common cowpea, boiled | 20 g | 25.0±1.65 | 14.9±3.51 | 3.72±0.39 |
| 37. Mung bean porridge | 125 g | 11.8±3.69 | 11.0±4.13 | 1.30±0.06 |
| 38. Black soybean, boiled | 20 g | 9.18±2.63 | 3.17±0.39 | 0.29±0.02 |
| 39. Broad bean, roasted | 60 g | 67.6±2.73 | 18.7±2.40 | 12.7±2.37 |
| 40. Broad bean, deep fried | 60 g | 58.7±8.19 | 13.1±1.99 | 7.72±1.24 |
| Tubers | | | | |
| 41. Potato sliced, boiled and cooled | 90 g | 17.5±2.13 | 4.37±0.58 | 0.77±0.09 |
| 42. Potato sliced, fried | 90 g | 16.4±2.31 | 5.19±1.08 | 0.85±0.08 |
| 43. Potato chips, deep-fried | 90 g | 54.8±3.71 | 9.05±0.59 | 4.96±0.87 |
| 44. Potato, steamed, cooled | 90 g | 18.7±3.82 | 31.0±0.95 | 5.80±1.28 |
| 45. Potato, roasted, cooled | 90 g | 36.5±8.43 | 52.5±2.97 | 19.2±1.68 |
| 46. Sweet potato, yellow skin, steamed, cooled(preservative) | 60 g | 25.9±0.51 | 13.1±2.13 | 3.39±0.32 |
| 47. Sweet potato, yellow skin, roasted (preservative) | 60 g | 46.1±9.91 | 4.59±0.90 | 2.11±0.24 |
| 48. Sweet potato, red skin, steamed (fresh) | 60 g | 22.0±1.57 | 5.13±1.03 | 1.13±0.06 |
| 49. Sweet potato, yellow skin, steamed(fresh) | 60 g | 11.8±0.33 | 12.0±2.82 | 1.41±0.07 |
| 50. Sweet potato slice, steamed and dried | 60 g | 43.4±2.17 | 8.95±0.26 | 3.88±0.26 |
| 51. Big taro, steamed | 60 g | 21.8±1.17 | 9.90±0.43 | 2.16±0.18 |
| 52. Taro, steamed | 60 g | 22.1±0.92 | 17.0±1.80 | 3.76±0.32 |
| 53. Yam slice, fried | 60 g | 12.1±0.30 | 24.8±4.44 | 3.01±0.26 |
| Starch products | | | | |
| 54. Mung bean starch noodle | 30 g | 67.2±3.94 | 34.1±7.13 | 23.0±1.35 |
| 55. Sweet potato starch noodle, broad, dried | 30 g | 96.8±0.59 | 41.0±4.10 | 39.7±2.02 |
| 56. Sweet potato starch jelly sheet, dried | 30 g | 98.9±4.47 | 31.6±4.60 | 31.3±1.56 |
| 57. Potato starch noodle, dried | 30 g | 98.2±5.50 | 27.8±1.44 | 27.3±1.32 |
| 58. Lotus root starch | 20 g | 98.0±1.43 | 5.34±1.36 | 5.23±0.98 |
| Vegetables | | | | |
| 59. Lotus root sliced, boiled and cooled | 100 g | 16.3±2.27 | 5.87±0.18 | 0.95±0.08 |
| 60. Lotus root sliced, fried | 100 g | 17.2±1.58 | 1.58±0.19 | 0.27±0.03 |
| 61. Silverweed cinquefoil, boiled | 200 g | 8.77±1.15 | 15.2±5.13 | 1.34±0.07 |

Table 2. Total starch and resistant starch in cooked food products[†] (con.)

| Food product and description | Serving size (g) | TS [‡] (g/100 g esculent) | RS [§] (g/100 g TS) | RS (g/100g esculent) |
|---|------------------|------------------------------------|------------------------------|----------------------|
| 62. Water caltrop, unshelled, dried, boiled | 200 g | 29.9±3.61 | 13.7±4.09 | 4.10±0.23 |
| 63. Water caltrop, steamed | 200 g | 20.2±2.62 | 12.4±0.96 | 2.50±0.26 |
| 64. Pumpkin, steamed | 200 g | 6.93±0.23 | 12.5±0.64 | 0.87±0.09 |
| 65. Chinese wax gourd, stewed | 200 g | 2.48±0.23 | 0.00±0.00 | 0.00±0.00 |
| 66. Yardlong cowpea, boiled and cooled | 20 g | 4.76±0.14 | 0.00±0.00 | 0.00±0.00 |
| 67. Pale green soybean, without seed coat | 20 g | 26.8±2.83 | 5.21±0.00 | 1.39±0.22 |
| Nuts and seeds | | | | |
| 68. Peanut kernel, deep-fried | 8 g | 29.3±4.21 | 15.1±1.52 | 4.41±0.43 |
| 69. Peanut, in shell, roasted | 14 g | 29.3±1.55 | 14.5±1.77 | 4.24±0.34 |
| 70. Peanut, boiled | 8 g | 29.3±1.10 | 14.7±2.22 | 4.32±0.32 |
| 71. Chestnut, in shell, fried with sugar | 35 g | 28.6±0.78 | 17.2±2.93 | 4.91±0.24 |
| 72. Pistachio, in shell, salted and roasted | 14 g | 15.6±1.01 | 21.9±3.24 | 3.43±0.38 |

[†] Values are means ± SD of five replicates

[‡] TS, total starch

[§] RS, resistant starch

be unable to penetrate or break down the cellulose cell walls and, therefore, this starch was inaccessible. For RS1, a starch physically entrapped within the food, the degree of milling was an important factor.^{21,22} More extensive milling should make these starches more accessible and less resistant to digestion.

Legumes

The RS levels of legumes varied from 11.4% to 32.3%. The presence of intact cell walls contributed to the RS content of legumes.

Tubers

The highest RS content, among the tuber products tested, was found in fresh potato (72.0%), which was almost six times higher than in the preserved sample. This might be due to starch hydrolysis to mono or oligosaccharides during the period of preservation. Big taro (44.1%) and sweet potato (30.1%) also had high RS content. Taro and yam had a similar RS content but taro showed a lower level of TS (18.8%) than yam (31.1%). Therefore yam provides significantly more nutritional value than taro.

Starches

As expected, pure potato starch (79.3%) and cassava starch (80.8%) had high RS concentrations.

Vegetables

Among the vegetables, water caltrop, silverweed cinquefoil, and pale green soybean showed high levels of RS.

Bananas

The RS concentration was almost ten times higher in unripe bananas than in ripe ones.

Nuts and seeds

Cashews and dried lotus seed had high RS contents.

Total starch and resistant starch in cooked foods

In Table 2, the TS and RS per 100 gm of cooked food and the average serving size of that food are listed for the 72 cooked foods products evaluated.

Cereals

Among cereal products, wheat and rice were the most important sources of starch in the Chinese diet. Daily intakes were estimated at 147 g and 74 g, respectively. The RS contents in the 31 cooked products included in the present study varied from 2.38% (total starch basis) to 16.4%. The high RS level in wheat starch jelly sheets was probably due to the degradation of the gelatinized amylose after thermal processing. Among the wheat products, wheat kernel porridge had considerable RS. Cakes, walnut cookies, fried dough twists, pancakes and biscuits had lesser, but significant, amounts of RS. In contrast, low concentrations of RS were found in buns (3.71%) and noodles (3.51%). This data indicates that baking and deep-frying catalyze RS formation. Among different porridges, purple long grained rice porridge, sorghum porridge, and buckwheat porridge also contained major amounts of RS. The contribution of RS from intact cereal grains to the diet was emphasized in a previous study.¹⁹

Legumes

Legume products were a main source of starch in the diets of the study subjects. In the present study, except for black soybean (3.17%) and roasted broad bean (18.7%), cooked legumes contained 11.0%-14.9% RS. Values in a similar range were reported for legume products by other laboratories using ileostomists.^{23,24} However, in the present study, the mean RS content of seven cooked legumes varieties (with the exceptions of black soybean and roasted broad bean) was higher (13.5%) than the mean value obtained in the previous study (11.7%) by Brighenti et al.¹⁶

Tubers

Tuber products were also an important source of starch in the subjects' diets. In our dietary survey, the daily intake was estimated to be 149 g. Potato and sweet potato accounted for 59 g and 56 g, respectively. The RS content in boiled potatoes and fried potatoes were similar, 4.37% and 5.19%, respectively. High RS levels were found in the deep-fried products, like potato chips (9.05%). Even higher RS contents were found in steamed and cooled

potato (refrigerated for 24 h) and roasted and cooled (in a refrigerator for 24h) potato, 31.0% and 52.5%, respectively, suggesting an influence of the deep-frying and roasting process on RS formation. According to Åkerberg et al,¹⁹ refrigeration of boiled potatoes might influence the formation of retrograded starch considerably. Therefore, when steamed or roasted potatoes were stored at 4°C for 24 h, the RS contents presumably increased considerably. The nature of the RS formed was probably retrograded amylopectin, since retrogradation of amylose is favored at around 100°C.²⁵ In addition, the RS fractions in the fried yam slices and steamed taro were also considerable.

Starch products

The daily intake of starch products by our subjects was estimated to be 46.9g. Sweet potato starch noodles (41.0%) and sweet potato starch jelly sheets (31.6%), both commercially processed starch products, were found to have higher levels of RS than sweet potato starch (28.9%). Mung bean starch noodles had surprisingly higher (31.1%) starch content than boiled mung bean (11.0%). The high RS levels in starch products were probably due to the retrogradation of the gelatinized starch after thermal processing.

Vegetables

Among the vegetables tested, water caltrop and silverweed cinquefoil showed high contents of RS. Boiled and cooled lotus root slices and pale green soybeans also had considerable RS. The percentage of RS based on total starch was high in steamed pumpkin, but it was not significant due to the small amount of total starch.

Nuts and seeds

The RS fractions in peanut, chestnut, and pistachio were high. But pistachio was infrequently consumed by the Chinese in our study.

Comparison of RS in raw food materials and cooked food products

Figure 1 illustrates changes in RS content due to cooking; in general, RS content was lower after processing. When starch is heated, starch granules swell and are disrupted. This process, known as gelatinization, makes the starch more accessible to digestive enzymes. When heated and gelatinized starch is cooled, retrogradation occurs and some of the gelatinized starch is converted to a crystalline form, which is resistant to digestion. Foods, such as bread, cold cooked potatoes, wheat starch jelly sheets, rice noodles, and sweet potato starch noodles, contain retrograded starch, which is resistant to digestion.

Cooking conditions are very important in determining the amounts of RS3 through gelatinization and retrogradation. Chewing also decreases the amount of RS present by reducing particle size.²¹

Kutoš et al.²⁶ evaluated common RS amounts in raw bean samples processed by different methods and verified that the amount was almost two times higher in raw samples than those that had been soaked and cooked. In contrast, however, when Tovar and Melitoevaluated the effect of thermal processing (conventional and at high pressure) on beans, these authors found values of RS three to five times greater in the cooked samples than raw.²⁷ The variation in the results may be due to the use of different methods of analysis. This emphasizes the need for methodological standardization.

Daily intake of resistant starch in Chinese study subjects

Xu et al.³¹ estimated the daily RS intake among a Chinese sample to be 14.9±9.1 g (16.2±8.8 g in male and 14.2±9.3 g in female, respectively). Obviously, RS intake will vary among individuals based on dietary habits. Table 3 summarizes the RS intakes in different areas of the world that have been reported in the literature. The level of RS intake was higher in Chinese subjects than Europeans

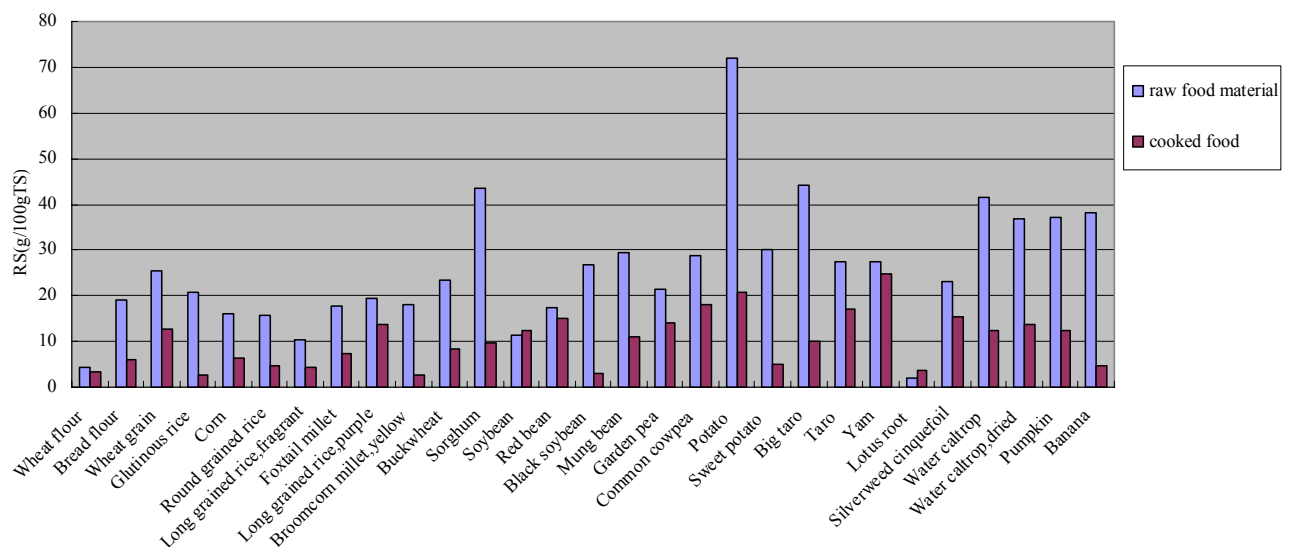


Figure1. RS content comparison in uncooked food materials and cooked food products

Figure 1. Comparison of RS content in raw and cooked food.*Value in cooked food was average content of food after processing in different ways ($p<0.01$)

Table 3. Resistant starch intake in different areas of the world

| Area | Information source | Intake (g/day) |
|------------------------|---------------------------|----------------|
| Africa | Cummings & Englyst (1989) | 20-30 |
| Europe | Englyst et al. (1992) | 3 |
| Ten European countries | Dysseler & Hoffem (1994) | 3.2-5.7 |
| Italy | Brighenti at al. (1998) | 8.5 |
| Sweden | Liljeberg (2002) | 3.2 |
| Global intake | Goldring (2004) | 3-10 |
| America | Murphy et al. (2008) | 3-8 |
| China | Liu et al. (2007) | 14.9 |

Table 4. Average daily intake of macro-nutrients and cholesterol for survey participants

| Classification | Total | Male | Female |
|-------------------|--------|--------|--------|
| Energy (kcal) | 2211.5 | 2379.6 | 2117.5 |
| (KJ) | 9253.2 | 9956.1 | 8859.5 |
| Protein (g) | 86.9 | 97.2 | 81.1 |
| Fat (g) | 80.9 | 76.1 | 83.5 |
| Carbohydrate (g) | 311.9 | 353.2 | 288.8 |
| Dietary Fiber (g) | 10.1 | 10.0 | 10.2 |
| Cholesterol (mg) | 467.5 | 500.9 | 448.8 |

(3.2g-5.7 g/day)¹⁵ and Americans (3g-8g/day)¹⁷ but lower than that in African studies (20g-30 g/day). RS intake is correlated with incidence of colorectal cancer, which is higher in Europe and lower in Africa.³²

Table 4 shows the average daily intakes per capita of macro nutrients and cholesterol for Chinese subjects in our study. We compared the diets of our subjects with recommended intake (RNI).²³ The percentage of energy provided by carbohydrates in diets of our subjects was close to the recommended daily allowances normal minimum. The percentage of energy provided by fat accounted for 32.9%, exceeding the adequate intake (AI) of 20%-30%.²³ Table 5 shows a menu that was typical of the food eaten by study subjects. The sources of RS in the Chinese diet in our study are shown in Figure 2. The main RS sources were cereals; including: wheat, rice, and corn. Cereals accounted for over half of the RS in the study

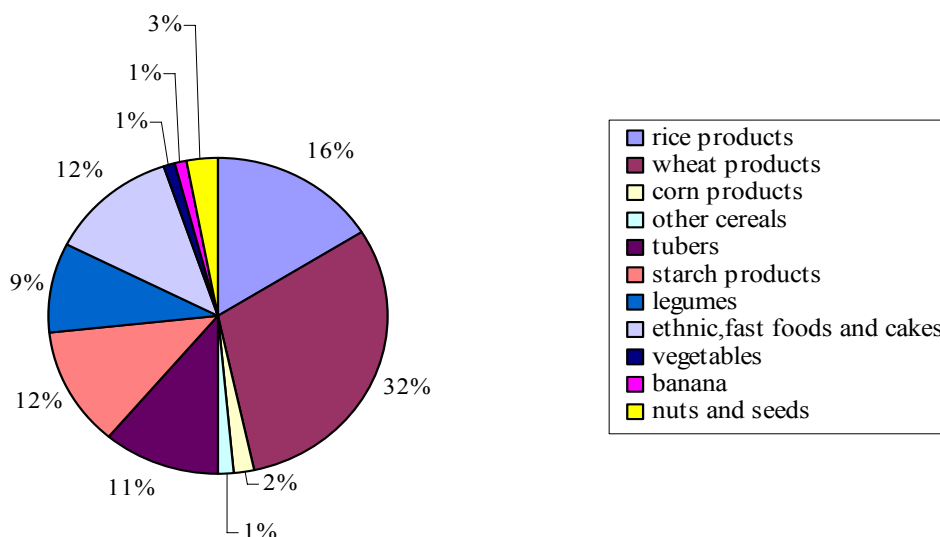
Table 5. Typical daily menu for a survey participant

| Meal | Food type | Serving size |
|-----------|---------------|--------------|
| Breakfast | Porridge | 50 g |
| | Pancake | 75 g |
| | Egg | 65 g |
| | Milk | 240 ml |
| | Noodle | 100 g |
| | Eggplant | 100 g |
| Lunch | Rice | 200 g |
| | Green Pepper | 80 g |
| | Egg | 50 g |
| | Garlic Sprout | 100 g |
| | Lean Meat | 30 g |
| | Porphyra | 5 g |
| Supper | Oil | 30 g |
| | Flour | 100 g |
| | Leek | 120 g |
| | Streaky Pork | 70 g |
| | Ribbonfish | 50 g |
| | Cucumber | 75 g |
| Snacks | Oil | 20 g |
| | Banana | 150 g |
| | Walnut kernel | 25 g |
| | Apple | 200 g |

subjects' diets. Other significant sources were ethnic foods, fast food and cakes.

CONCLUSION

This study is the first evaluation of the RS content of a Chinese diet. RS intake has implications for colonic health and glucose as well as lipid metabolism; and most diets do not contain enough of this starch fraction. In the present study, we evaluated the RS content of foods typically consumed by our Chinese subjects. The RS content varied with plant source. In general, tubers and legumes had more RS than cereals. Among the selected foods, potato showed the highest amount of RS. Commercially processed starch products were found to have a higher RS content than products prepared via methods used in private kitchens. In general, cooking decreased RS content. Although deep-fried and roasted foods had more RS than

**Figure 2.** The sources of resistant starch in diets of study subjects

braised foods, it should be emphasized that deep-fried products also had a high fat content. Hence, an increased intake of such products should not be encouraged. Legumes are a good source of RS. It would be prudent to recommend increased consumption of tubers, legumes and cereal grain products.

In order to estimate the daily RS intake in the Chinese population, food consumption data from dietary surveys of men and women from both city and country areas were used. A mean RS value was calculated from the analyzed individual products in each food group. The daily RS intake was estimated to be 14.9±9.1 g. Obviously, RS intake varied considerably among individuals. The main RS sources in the Chinese diet were wheat products, rice products, and starch products. Other important sources of RS were tubers and legume products, followed by corn products and other cereals, nuts and seeds. The estimate of resistant starch intake provides a valuable reference for researchers and food and nutrition professionals and will allow for more accurate estimates of total intakes of carbohydrate compounds that escape digestion in the small intestine.

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AUTHOR DISCLOSURES

The authors have declared no conflict of interest.

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Short Communication

Sources and intake of resistant starch in the Chinese diet

Liyong Chen MD¹, Ruiping Liu MD², Chengyong Qin MD¹, Yan Meng MPH³, Jie Zhang MPH¹, Yun Wang MPH³, Guifa Xu MD³

¹Nutritional department of Provincial hospital affiliated to Shandong University, Jinan, China

²Nutritional department of Xian Children's Hospital, Xian, China

³Institute of Nutrition and Food Hygiene of Shandong University, Jinan, China

中国居民膳食中抗性淀粉摄入量及食物来源

抗性淀粉在小肠中不能被消化，而在大肠中可能被酵解。本研究的目的是测定特定食物中的抗性淀粉的含量，并估计中国居民每人每日抗性淀粉摄入量，以及提供抗性淀粉的主要食物来源。用体外模拟胃肠道酶解法对 121 种常用食物中的抗性淀粉含量进行测定。根茎类和豆类食物中抗性淀粉含量较高。粗加工食物中保留较多抗性淀粉。食物经过烹调加工后，抗性淀粉含量普遍降低。油炸和烘烤的食物较蒸煮的食物抗性淀粉含量较高。根据膳食调查来估计，中国居民抗性淀粉的平均摄入量为每日 14.9 g。中国居民膳食抗性淀粉的主要来源为面制品、米制品和淀粉产品类。居民的抗性淀粉摄入量因为饮食习惯的差异个体差异较大。

关键词：含量、膳食调查、摄入量、抗性淀粉、来源