Food Research 7 (1) : 144 - 150 (February 2023)
Journal homepage: https://www.myfoodresearch.com

FOOD RESEARCH

FULL PAPER

Effect heat moisture treatment for resistant starch levels and prebiotic properties of high carbohydrate food: meta-analysis study

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Article history:
Received: 30 November 2021
Received in revised form: 1 January 2022
Accepted: 8 April 2022
Available Online: 3 February 2023

Keywords:
Heat moisture treatment,
High carbohydrate foods,
Meta-analysis,
Resistant starch,
Starch modification

DOI:
https://doi.org/10.26656/fr.2017.7(1).928

Abstract

Heat moisture treatment is one of the physical modification techniques of starch that is widely used in assessing the increase in resistant starch levels in foodstuffs. However, this technique has different effects on each type of high-carbohydrate food. This study aimed to analyze the type of carbohydrate food that has a significant effect in increasing the levels of resistant starch and prebiotic properties by heat moisture treatment techniques. This study used fourteen articles which were analyzed and selected through the PRISMA guide method from a total of 531 articles obtained. The data was analyzed based on the percentage value of the Hedges' effect size (standardized mean difference/SMD) and the value of the confidence interval (CI) using the OpenMEE software. The meta-analysis showed that the heat moisture treatment method on high-carbohydrate foods had a significant effect on increasing the levels of resistant starch and prebiotic properties (SMD 4.045; 95% CI: 2.301 to 5.788; p<0.001). The conclusion of this meta-analysis was that heat moisture treatment had a significant effect with a 95% confidence level in increasing resistant starch levels and prebiotic properties in high-carbohydrate foods.

1. Introduction

Resistant starch is a starch fraction that cannot be digested by digestive enzymes and is resistant to gastric acid. It can reach the large intestine to be fermented by probiotic bacteria. According to Sajilata *et al.* (2016), resistant starch is a starch fraction that cannot be digested by enzymes in the small intestine. It has physiological effects that are beneficial to health such as the prevention of colon cancer and has hypoglycemic and hypocholesterolemic effects. Starch is categorized based on its digestibility by amylase enzyme to be converted into monosaccharide (glucose) (Lombu *et al.,* 2018). It can be classified into Very Rapid Digestibility Starch (VSDS) for starch which is digested in under 1 min by the enzyme amylase, Rapid Digestibility Starch (RDS) for starch which is digested within 1 - 20 mins by the enzyme amylase, Slow Digestibility Starch (SDS) for starch which is digested within 20 - 120 mins by the amylase enzyme, and Resistant Starch (RS) for starch that cannot be digested by the amylase enzyme above 120 mins (Sajilata *et al.,* 2016).

The principle of physical modification, in general, is by heating. Physical modification treatments include extrusion, parboiling, steam cooking, microwave irradiation, roasting, and hydrothermal treatment. Most of the physical modification methods that have been mentioned can increase the levels of resistant starch (Sajilata *et al.*, 2006). Another physical treatment is the autoclaving method which can increase the production of resistant starch by up to 9% (Sajilata *et al.,* 2016).

Heat Moisture Treatment (HMT) is a process of heating starch at a high temperature above the gelatinization temperature in a semi-dry condition, which is a lower water content (18-30%) than the conditions required for the gelatinization process to occur (Cheng *et al.,* 2019). Deka and Sit (2016) reported that the HMT technique is a process of heating starch at high temperatures above the gelatinization temperature (84–140°C) with limited moisture content (11–28%) for 15 mins to 16 hrs. The HMT technique can increase the gelatinization temperature, increase the viscosity of the starch paste, and increase the tendency of the retrogradation process (Gonzalez *et al.,* 2007).

Generally, it was reported that HMT decreased peak viscosity and breakdown viscosity, increased

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eISSN: 2550-2166
Published by Rynnye Lyan Resources

gelatinization temperature, and decreased swelling power capacity of starch granules (Cheng *et al.,* 2019). Under HMT conditions, starch was not fully gelatinized and only partially gelatinized due to limited starch water content. There were several changes during the starch modification process with HMT, the formation of amylose-lipid complexes and a decrease in the enzymatic hydrolysis of starch (Cheng *et al.,* 2019). HMT induces changes in the regulation of amylose and amylopectin chains in starch granules resulting in changes in granular swelling, increasing starch crystallinity, and triggering starch retrogradation (Hoover *et al.,* 2010). Decreased starch digestibility, increased crystallinity and increased interactions between starch chains through the formation of double-helical bonds will increase RS3 levels. The RS3 component formed by the HMT process is very difficult to digest by pancreatin amylase. This causes HMT taro starch to be more resistant to the hydrolysis of gastric acid and digestive enzymes in the small intestine. It can reach the colon and be fermented by probiotic bacteria such as *Lactobacillus* sp. and *Bifidobacterium* sp. that live in the colon.

Foods with low digestibility, are good for diabetics, or those who are on a low-calorie diet. The characteristics of forage-modified food are influenced by several factors, including the type of food and pH (Setiarto *et al.,* 2015). This study aimed to analyze the type of food with high carbohydrate content which has a significant effect in increasing the levels of resistant starch and prebiotic properties by heat moisture treatment techniques.

2. Materials and methods

2.1 Materials and facilities

The materials used in this meta-analysis study are research articles from reputable and accredited international publications from various online database web servers such as Science Direct, Wiley Online Library, Taylor and Francis Online, Springer Link, and Google Scholars.

The tools used are Mendeley software (version 1.19.8 (2020), Zotero (version 5.0.97(2021)), OpenMEE software (version 10.10 (2020)), Microsoft Excel (version 16.53 (2019)). Mendeley and Zotero were used for selecting literature studies, while Microsoft Excel and OpenMEE were used to analyze the data.

2.2 Reference analysis strategy

The analysis and selection of the literature were carried out by following the rules of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), a series of analytical processes to select the desired library. PRISMA rules are used to facilitate reporting of the research journal selection process. The library selection is divided into several stages, selection based on title and duplication, selection based on abstract, selection based on method, and full-text selection. The literature was searched through the web server database Science Direct, Wiley Online Library, Taylor and Francis Online, Springer Link, and Google Scholars, using the keywords "physical modification of starch, heat moisture treatment and prebiotic properties". The three keywords are combined using a Boolean operator with the expression "and" then added a selection in the form of the year of publication (2011-2021) to narrow the search.

2.3 Selection of references/ study articles

The selection of research literature was carried out based on the screening of titles and abstracts and then thoroughly analyzed to determine their suitability with the inclusion and exclusion criteria that had been set. The inclusion criteria used were literature from reputable international journals. The selected study is also the result of primary data research published in the last 10 years (2011-2021). It has data on levels of resistant starch before modification (control data) and after modification (experimental data), and is limited to studies using heat moisture treatment techniques. Exclusion criteria used included starch modification methods, analysis of prebiotic properties, and study of research results with additional treatment procedures other than heat moisture treatment (such as debranching, lintnerization, and annealing).

2.4 Data collection

The research data in the selected study from the journal webserver using Zotero's assistance was then extracted into a Microsoft Excel worksheet. Data were collected based on the author's name, year of publication, food ingredients, a mean and standard deviation of control and experimental resistant starch levels, and the number of replications.

2.5 Statistical analysis

The data were analyzed using the Hedges'd effect (Standardized Mean Difference/SMD) with a 95% confidence interval by analyzing the Effect Size of the data using OpenMEE. The data taken from the selected journals are the mean, standard deviation or standard error, and the number of repeated attempts. SMDs with appropriate 95% CI values were pooled using a random-effects model. Higgins and Thompson (2016) reported that the exploration of heterogeneity across studies is carried out using an index of I^2 (I^2> 50% indicates sufficient heterogeneity).

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3. Results and discussion

3.1 Selection of references/study articles

The libraries obtained from the selection process in the database are 531 libraries. Overall, the libraries were entered into the Zotero software to remove the same duplicate libraries and get 320 libraries, then proceed with the selection based on the abstracts obtained by 142 libraries. The results of the next selection eliminated 128 libraries because they did not analyze prebiotic properties and did not include complete quantitative data in the form of resistant starch content data before modification (control data) and after modification (experimental data). Library selection is also carried out based on literature published in reputable international databases. The selected library is also the result of primary data research published in the last 10 years (2011-2021) and is limited to studies using heat moisture treatment techniques. A total of 14 complete libraries used as relevant material in meta-analysis research can be seen in Figure 1.

3.2 Data analysis

The data from the analysis of resistant starch content from each selected library was obtained from as many as fourteen data. The summary of the data for each study can be seen in Table 1. The whole data is then processed in the OpenMEE worksheet to determine the Effect Size value, heterogeneity/inconsistency value (I^2), and p-value. The Effect Size values from each study were re-analyzed using OpenMEE to determine the combined effect measurement value with a 95% confidence interval (CI) with a significance level of 0.05. The Effect Size value is the Hedges'd (Standardized Mean Difference/SMD) value to analyze the effect of related treatments.

The heat moisture treatment technique is carried out using low water concentrations (18.21, 24.27%) and the hydrothermal technique can affect the gelatinization characteristics of starch which is the main characteristic of resistant starch (RS) type 3 (Wang *et al.,* 2019). According to Piecyk *et al.* (2021), RS 3 is the most resistant starch fraction, especially in the form of retrograded amylose formed during the cooling of gelatinized starch, as well as at room temperature. The heat moisture treatment process can lead to the formation of more retrograded or crystallized amylose fractions (Aparicio *et al.,* 2005). The formation of RS 3 by recrystallization and retrogradation processes is the main cause of increasing levels of resistant starch in foods (Chang *et al.,* 2020). The hypothesis tested in the meta-analysis study was that the greater the increase in the level of resistant starch, the higher the effect of modified heat moisture treatment techniques on foods.

The results of the forest plot meta-analysis using OpenMEE (Figure 2) showed that there was a significant effect in the heat moisture treatment process on increasing levels of resistant starch, with the combined SMD effect value of 4.045 with 95% CI (2.301 to 5.788) p<0.001 and the heterogeneity value (I^2) was categorized as high (90,498 I^2). The meta-analysis used Continuous Random-Effects Model analysis to see differences between one study and another. The heterogeneity value is needed to see the diversity between the analyzed studies. Wallace *et al.* (2017)

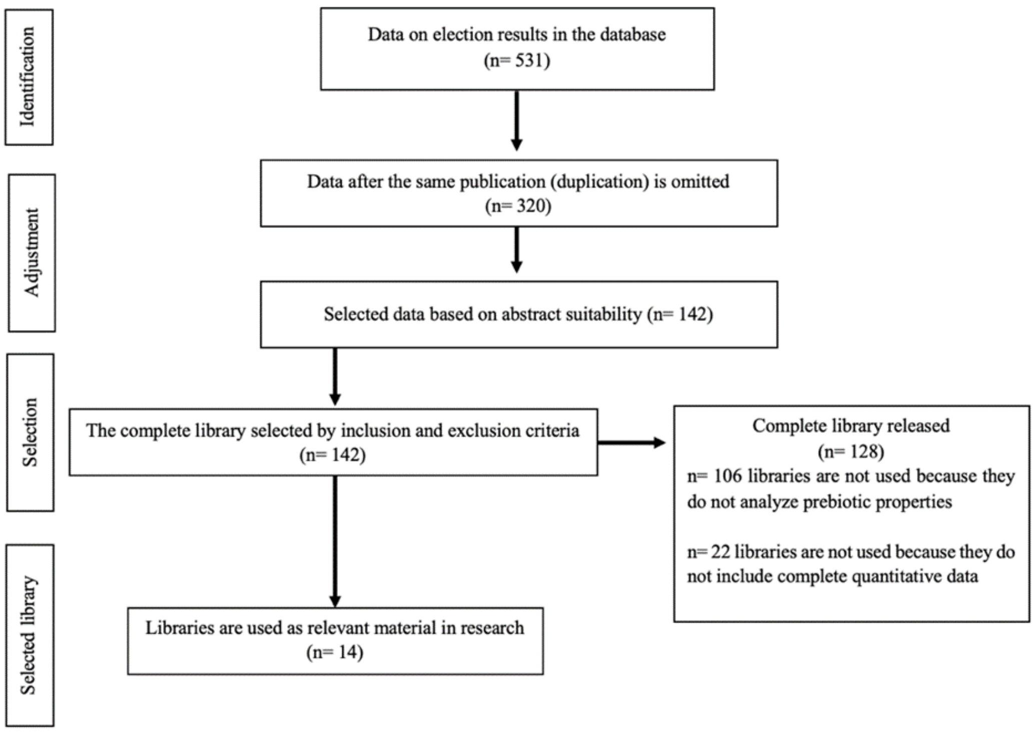

Figure 1. The process of selecting literature/study articles for further meta-analysis

https://doi.org/10.26656/fr.2017.7(1).928

reported that a meta-analysis study can be said to be good if it has a heterogeneity value close to 100%. The higher the heterogeneity value between studies, the more heterogeneous and can represent the diversity of the data from each study.

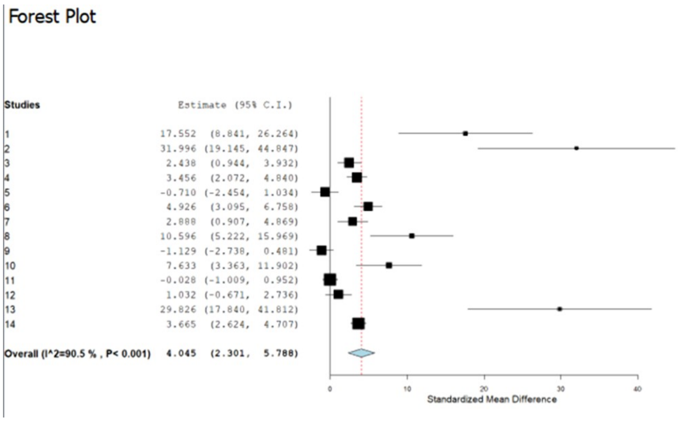

Figure 2. Forest plot of the results of the meta-analysis study of all data

Effect Size value data indicate that in general the results of the meta-analysis support the theory that the relationship between modified heat moisture treatment techniques and increased levels of resistant starch is interrelated. 3 data are not by the theory, the data in study 5 from Garcia-Valle *et al.* (2021), 9 from Vatanserver *et al.* (2021), and 11 from Wang *et al.* (2016) showed a decrease in resistant starch levels in foodstuffs. An indication of a decrease in resistant starch levels which after modification was related to the degradation process of RS 1 and RS 2 which was more dominant was a decrease due to excessive heating which caused a decrease in the percentage of chain distribution with a degree of polymerization (DP) 25-30. At the time of starch gelatinization, the birefringence properties of starch granules are lost due to the addition of excess water and heating at a certain time and temperature. The starch granules swell and cannot return to their original condition (irreversible) (Zabar *et al.,* 2008). Heating the starch suspension above the gelatinization temperature can cause hydrogen bonding to break.

3.3 The effect of differences in carbohydrate foods on increasing levels of resistant starch

Table 1 presents fourteen study data that reported an increase in resistant starch levels after the modified heat moisture treatment technique was carried out. A total of 78.57% of study data reported that there was an increase in levels of resistant starch and 21.43% of study data reported that there was a decrease in levels of resistant starch in the foods. A total of 14 types of carbohydrate foods were used in the study, each of which gave different results on increasing levels of resistant starch either before or after the modified heat moisture treatment technique was carried out. Zabar *et al.* (2008) reported that the difference in the increase in levels of resistant starch is due to differences in the content of amylose and amylopectin levels of food ingredients. Afolabi *et al.* (2018) added that in addition to the levels of amylose and amylopectin modified starch, it was also influenced by several factors such as reducing sugar content, starch digestibility, starch composition, fibre content, starch gelatinization, and starch retrogradation. Forest plot data analysis results from the effect of different types of carbohydrate foods are presented in Figure 3.

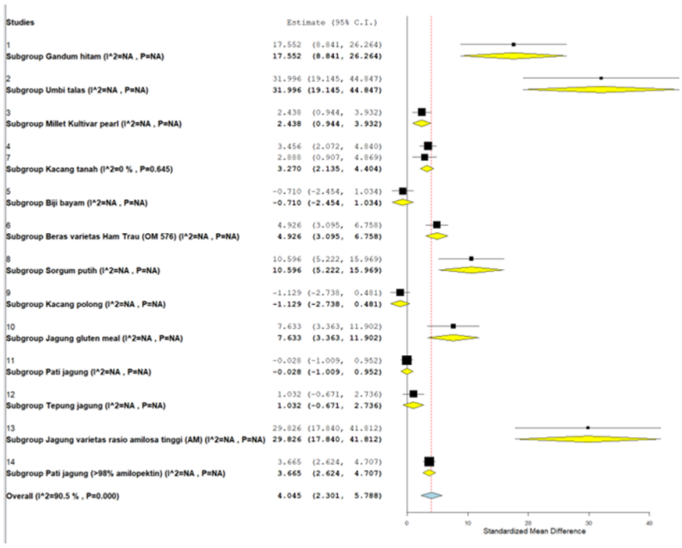

Figure 3. Forest plot of the results of the meta-analysis of the study of the effect of different types of carbohydrate foods

The results of the forest plot showed that high-carbohydrate foods had a significant effect on increasing levels of resistant starch with an SMD effect value of 4.045 with 95% CI (2.301 to 5.788) p<0.001 and the heterogeneity value (I^2) was categorized as high (89.00 I^2). The results of the forest plot for the carbohydrate food subgroup data show that in general, the modified heat moisture treatment technique for the whole food material had a significant effect on increasing levels of resistant starch.

3.4 Effect of high carbohydrate foods on prebiotic properties

Further analysis was conducted to determine the effect of the type of high carbohydrate foods on the prebiotic properties. Each test of prebiotic properties which is divided into the starch composition (SC), amylose interaction (Al), the viability of lactic acid bacteria (VBAL), the viability of Enteropathogenic Escherichia coli (VEPEC) in the literature are analyzed and the forest plot data can be seen in Figure 4. Based on the results of the forest plot, it can be seen that high-carbohydrate foods with an SMD effect value of 4.045 with 95% CI (2.301 to 5.788) p<0.001 had a significant effect on prebiotic properties with an SMD effect value of 4.045 with 95% CI (2.301 to 5.788) p<0.001. The effect size value of foods has an equation with the effect

https://doi.org/10.26656/fr.2017.7(1).928

Table 1. Data on changes in levels of resistant starch in foodstuffs

No.	Foodstuffs	Resistant starch control (%)	Resistant starch after modification (%)	Change in resistant starch (%)	Literature study
1	Buckwheat	80.11	89.12	112.47	Goel *et al.* (2020)
2	Taro tubers	91.48	97.94	70.61	Deka *et al.* (2016)
3	Millet Cultivars pearl	16.70	20.40	221.55	Sandhu *et al.* (2020)
4	Peanuts	44.00	41.00	73.17	Piecyk *et al.* (2021)
5	Spinach seeds	58.90	41.13	-17.77	Garcia-Valle *et al.* (2021)
6	Ham Trau variety rice (OM 576)	11.80	18.70	584.74	Hung *et al.* (2016)
7	Peanuts	33.00	44.64	352.27	Afolabi *et al.* (2017)
8	White Sorghum	10.10	12.30	217.82	Cervini *et al.* (2021)
9	Peas	40.69	30.00	-26.27	Vatansever *et al.* (2021)
10	Corn gluten meal	16.58	19.93	202.05	Liu *et al.* (2015)
11	Corn starch	6.99	5.07	-27.46	*Wang et al.* (2016)
12	Corn starch	46.70	48.50	38.54	Massarolo *et al.* (2019)
13	Corn varieties high amylose ratio (AM)	87.45	94.08	75.81	Li *et al.* (2015)
14	Corn starch (>98% amylopectin)	60.11	85.90	42.90	Chang *et al.* (2020)

The average increase in resistant starch (n = 12); 181.08 %
The average decrease in resistant starch (n = 3); -22.02 %
Total n = 14; increase in resistant starch (n = 26) 78.57 %; decrease in resistant starch (n = 3) 21.43 %

size values of prebiotic properties, which means that high carbohydrate foods have a comparable effect on prebiotic properties. According to Borenstein *et al.* (2009), the effect size value describes the average of each meta-analysis study that can be distributed as a whole.

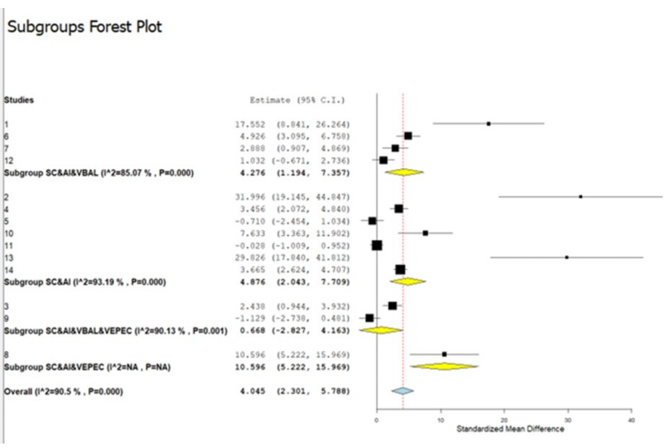

Figure 4. Forest plot of the results of the meta-analysis of the study of the effect of carbohydrate foods on prebiotic properties

4. Conclusion

The physical modification technique with heat moisture treatment for high-carbohydrate foods has a significant effect in increasing the levels of resistant starch by interpreting the data on the significance effect value in increasing the levels of resistant starch (HR 4.045; 95% CI): 2,301 to 5,788; p<0.001) and heterogeneity value (I^2) 90,498. The high carbohydrate foods with an SMD effect value of 4.045 with 95% CI (2.301 to 5.788) p<0.001 had a significant effect on improvement prebiotic properties with an SMD effect value of 4.045 with 95% CI (2.301 to 5.788) p<0.001. The conclusion from this meta-analysis study is that the heat moisture treatment has a significant effect with a 95% confidence level in increasing the levels of resistant starch and improvement of prebiotic properties in high-carbohydrate foods.

Conflict of interest

The authors declare no conflict of interest.

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