

Title: Morphological, physicochemical, and functional properties of fifteen different dietary carbohydrate sources in Sri Lanka

Short running title: Comparison of fifteen different carbohydrate sources in Sri Lanka

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Conflict of interest

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Abstract

BACKGROUND: Carbohydrate is the primary source of energy in the human diet and plays an important role in a healthy diet. In this study, fifteen different carbohydrate sources (White raw rice, Red raw rice, White Basmati rice, Red Basmati rice, Wheat, Atta flour, Soy, Black gram, Corn, Finger millet, Water lily seeds, Kithul, Chickpea, Oats, and Palmyra sprouts) in Sri Lanka were investigated for their physicochemical and functional properties. **RESULTS:** The shape of the extracted starch granules varied according to the source, and the amylose content ranged from 17.22% to 36.12%. Kithul and Black gram showed the highest water swelling capacity and water absorption index, respectively. Flour of White raw rice and Finger millet showed significantly higher ($p < 0.05$) freeze-thaw stability than other sources. Flour of Soy, Black gram, and Chickpea showed significantly higher ($p < 0.05$) dietary fiber content and potassium content than other samples. Water lily seeds showed remarkable *in vitro* prebiotic activity from the studied carbohydrate sources. **CONCLUSION:** The study indicates the potential utilization of raw White

rice, Palmyra, and Finger millet starch in the food processing industry as alternatives to conventional starch sources. Furthermore, the flour from Water lily seeds, White basmati rice, Soy, and Black gram has the potential for use in functional food preparation, offering a wide range of health benefits.

Keywords: Carbohydrate, Sri Lanka, dietary fiber, prebiotic activity, physicochemical properties,

1. Introduction

Dietary carbohydrates play a significant role in developing type 2 diabetes and its associated health complications^{1,2}. Systematic reviews and meta-analysis revealed that the type of carbohydrate (whole grain, refined grain, fruits, vegetables), their quality (glycemic index, glycemic load), and the composition (vitamin, minerals, dietary fiber, prebiotics content) critically influence the health³. In Sri Lanka, rice is the staple diet, and refined wheat flour is highly used in the bakery industry. The consumption of other carbohydrate sources is reported in lesser quantities. According to Jayawardana et al.⁴, Sri Lankans consume many starch servings; nearly 65% of adults consume well above the upper cut-off recommendation. It is widely believed that the high prevalence of diabetes in the country is closely associated with this dietary pattern. Although there are diverse starch sources in Sri Lanka, they remain underutilized with unknown properties⁵. Therefore, manipulating the main dietary component in the Sri Lankan diet: the carbohydrate portion, could be an excellent strategy to address the issues related to nutritional disorders.

This research compared the physicochemical and functional properties of commonly available fifteen dietary carbohydrate sources in Sri Lanka. Four rice varieties (*Oryza sativa*): Red raw rice, White raw rice, White basmati rice, and Red basmati rice; three legumes: Soy (*Glycine max*), Black

gram (*Vigna mungo*), Chickpea (*Cicer arietinum*); several other kinds of cereals: Oats (*Avena sativa*), Finger millet (*Eleusine coracana*), Corn (*Zea mays*), Refined wheat flour, Whole grain wheat flour (*Triticum aestivum*); and some other sources: Palmyra (*Borassus flabellifer*) sprouts, White water lily (*Nymphaea pubescens*) seeds, and Kithul (*Caryota urens*) were selected for the study. Out of these fifteen sources, Finger millet, Palmyra, Water lily seeds, Black gram, and Kithul have been identified as non-conventional and underutilized sources which has a huge potential in various industrial applications.

There is an emerging trend to recognize new starch sources suitable for food and non-food applications ⁶⁻⁹. In addition, bioactive carbohydrates such as dietary fiber, prebiotics, and oligosaccharides are well-recognized for their health benefits ¹⁰. Further, the prebiotic activity of the carbohydrate sources mentioned above is minimally discussed in the literature. Thus, this study provides a meaningful comparison between the available carbohydrate sources in Sri Lanka to explore the potential of utilization for industrial applications and functional food preparation.

2. Materials and Methods

2.1 Chemicals

Heat stable α -amylase (A3306), amyloglucosidase (A9913), protease (P3910), celite acid washed (C8656), pancreatin (218411), and pepsin (77160-100G) were purchased from Sigma-Aldrich (St. Louis, MO, USA). Freeze-dried probiotic culture of *Lactobacillus acidophilus* (LA-5), *Bifidobacterium animalis* subsp. *lactis* (nu-Trish BB-12) were obtained from CHR HANSEN holdings A/S, Denmark. Culture media: Lactobacillus MRS agar, Modified Bifidobacterium agar, Peptone-bacteriological, and Lactobacillus MRS broth were bought from HiMedia Laboratories

Pvt Ltd. All other chemicals were in analytical grade and purchased from Sigma Aldrich (St. Louis, USA) unless otherwise stated.

2.2 Sample collection and preparation

Fifteen different carbohydrate sources available in Sri Lanka were selected for the study. Fresh seeds and grains: Corn-Ruvan, White water Lilly seeds, Black gram-Anurada, Soy-PB1, Chickpea, and Finger millet- Oshada were purchased from the Palwehera seed farm, Dambulla, Sri Lanka. Kithul, Wheat flour, and whole grain wheat/Atta flour were obtained from the local market in Sri Lanka. Oats, and rice varieties: White basmati rice, Red basmati rice, White raw rice-Nadu, and Red raw rice-Kekulu were purchased from the local market. Palmyra sprouts were acquired from a household in Jaffna, where it is grown abundantly. Samples were oven-dried at 60°C and ground and sieved to separate the particles range in 100-150µm.

2.3 Isolation of starch

Starches were extracted using the alkali method as described by Noor et al.¹¹ with slight modifications. Ground flour samples were soaked in 0.5% NaOH solution for 6hrs at room temperature with continuous agitation. The slurry was then filtered through a 100mm-mesh stainless sieve and allowed to settle overnight at 4°C. The supernatant was discarded, and the precipitate was washed three times with distilled water and then dried at 40°C for 24hrs.

2.4 Starch granular morphology

Granular morphology of the isolated starch was observed using scanning electron microscopy (SEM) (EVO LS15, Carl Zeiss, Jena, Germany). Starch samples were applied on an aluminum stub using a double-sided adhesive tape and then coated with a thin film of gold. The images were recorded at ×10,000 magnification.

2.5 Determination of Amylose content

The amylose content of the starch sources was determined using the Megazyme amylose/amylopectin assay kit (Megazyme Ireland International, Ltd.) by following the manufacturer's instructions. All analyses were carried out in duplicates.

2.6 Physicochemical properties

2.6.1 Freeze–thaw stability

Flour gel preparation was conducted according to the procedure described by Charoenrein et al.¹² with minor modifications. Briefly, flour suspension (9% w/w wet basis) was heated at 85°C for 25 minutes with interval agitation. Then the samples were incubated at 25 °C for 2 hrs and frozen at -18°C for 22 hrs. Then samples were thawed at room temperature for 2 hrs. Five freeze-thaw cycles were performed, and samples were centrifuged at 2200 rpm for 30 min. The syneresis of the freeze-thaw flour gel was measured as the percentage of water released after centrifugation.

2.6.2 Water swelling power and solubility index

Water Swelling Power (WSP) and Solubility Index (WSI) was performed according to the method described by Wani et al.¹³. The 2% (w/v) starch dispersions were used for the analysis and transferred to a centrifugal tube. Then it was heated in a water bath at 90°C for 30 min. Afterward, samples were cooled to room temperature and centrifuged at 3000 rpm for 15 min. Then the supernatant was separately collected into a pre-weighted petri dish. The weight of the wet sediment was recorded, and the supernatant was dried at 110 °C for 24hrs.

2.6.3 Water absorption capacity

Water absorption capacity was determined according to Wani et al.¹³ with minor modifications. The starch suspension (1/8 (w/v) in distilled water) was stirred for 30 min at room temperature and

then centrifuged at 3000g for 10 min. Afterward, the supernatant was separated, and the weight gain was expressed as water absorption capacity.

2.7 Determination of functional ingredients

2.5.1. Determination of Dietary fiber composition

Dietary fiber contents were investigated by the enzymatic gravimetric method as previously described by Proskey et al.¹⁴ specified in (AOAC (2012)-991.43) using a dietary fiber assay kit (Sigma-Aldrich, TDF 100A-1KT). Duplicates were performed for each sample, and total dietary fiber (TDF) and insoluble dietary fiber (IDF) contents were assessed. The soluble dietary fiber (SDF) content was obtained by the difference between TDF and IDF fractions.

2.5.2 Quantification of mineral

The digestion was performed according to Sarikurkcu et al.¹⁵ using a microwave-assistant closed vessel digestion system (MARS, CEM Corporation, North Carolina). Conditions for the microwave system were: Ramping at 180°C for 15min, holding at 180°C for 10min, and cooling for 15min. Duplicates were performed for each sample and analyzed for Ca, Mg, K, Na, Zn, Fe, Zn, Mn, and Cu by Inductive coupled plasma-optical emission (ICP-OES) (iCPA 7000 series, Thermo Scientific). Multi-element standard solution 5 for ICP was used as the standard reference material for the calibration.

2.5.3 Determination of Prebiotic activity

In-vitro digestion of the starch sources

In-vitro digestion was performed according to the procedure of Sayar et al.¹⁶ with some modifications. Briefly, ground samples were digested with synthetic enzymes: α - amylase

(5mg/mL), pepsin (0.5 mg/mL), and pancreatin (0.5 mg/mL) sequentially at relevant pH and facilitated continuous agitation. Then the slurry was centrifuged, and the pellet (insoluble part) and supernatant were separately collected. Then the supernatant was mixed with 95% ethanol four times and subjected to centrifugation again. Afterward, two pellets were collected and oven-dried at 50°C to obtain a fine powder.

Prebiotic activity assessment

The prebiotic effect was assessed by evaluating the proliferation of pure culture probiotic bacterial strains: *Bifidobacterium animalis* subsp. *lactis* (BB-12) and *Lactobacillus acidophilus* (LA-5) in the presence of 1% (W/V) of each *in-vitro* digested starch substrate and glucose. The assay was performed according to the methodology reported by Huebner et al.¹⁷ Bifidobacterium agar and Lactobacillus agar media were used for plating *B. animalis* and *L. acidophilus*, respectively. Plates having bacteria colonies within 25-250 were selected for calculations. Before the statistical analysis bacteria counts in the agar plates were transformed into log₁₀ CFU/mL values.

2.6 Statistical Analysis

A complete randomized design was conducted for both analyses. All data were statistically analyzed by one-way analysis of variance (ANOVA) using SAS software (SAS 9.3.1). Significant differences among means were separated by Duncan's multiple range tests. Differences at $p < 0.05$ were considered significant.

Results and Discussion

Starch granular morphology

The granular morphology and size distribution in starch critically influences for the physicochemical properties including swelling power, enzymatic digestibility, and water holding capacity¹⁸. Morphological features of the extracted starch granules observed under the SEM are shown in **Figure 1**. Typical micrographs showed that the shape and size of starch granules differ according to the botanical source. The average area distribution of starch granules ranged from 12.22 - 1457.20 μm^2 . Wheat and whole grain wheat flour showed spherical-shaped granules, while Kithul showed both elongated and spherical granules. Rice starches: Red raw rice, White raw rice, White Basmati, Red Basmati, and other cereal starches: Finger millet and Corn showed polygonal shaped granules. Legume starches: Black gram and Chickpea showed elongated granules. Palmyra had both irregular shapes large granules, and small elongated granules. Kithul, Chickpea, and Black gram had comparatively larger granules, while rice starches had smaller granule sizes. The observed granule morphology of Wheat, rice starches, and Finger millet was in agreement with the previous reports by Chakraborty et al.¹⁹ and Verma et al.²⁰

Amylose content

Starch is composed of two glucose polymers: linear amylose and branched amylopectin. The ratio between amylose and amylopectin is accountable much for its functionality²¹. According to **Table 1**, the amylose content in different dietary sources ranged from 17.22-36.12%. Palmyra had the highest amylose content, followed by Whole grain wheat flour (33.45%) and Black gram (32.95%). Soy showed the lowest amylose content of the studied samples. The amylose content in four rice varieties ranged from 19-31%. The obtained amylose content for the Soy, Black gram, and Wheat in this study complied with the findings of Stevenson et al.²², Singh et al.²³ and Soh et al.²⁴ respectively. However, the amylose content of Finger millet was higher than the value

reported in Jayawardana et al.²⁵. The discrepancies in amylose content could have related with the difference in variety, environmental factors, and the method employed for the determination²⁶.

Water swelling capacity, water absorption index, and solubility index

Water Swelling Capacity (WSC) and Water Absorption Index (WAI) are two important indices that estimate the suitability of a material for use as a stabilizer or binder. According to the data (**Figure 2**), Kithul showed the highest WSC (13.2 g/g), followed by Palmyra (11.82 g/g) and Finger millet (10.42 g/g). Soy showed the least WSC (2.99 g/g) from the studied sample. Considering the WAI, Black gram showed the highest value (3.74 g/g), followed by Palmyra (3.55 g/g), Soy (2.61 g/g), and Finger millet (2.65 g/g). Wheat showed the lowest WAI among the studied samples. The discrepancies between WSC and WAI are associated with the different interactions of starch with cold water and hot water. Generally, starch is insoluble in cold water, and solubility occurs in hot water, where starch granules begin to swell rapidly only after the temperature reaches gelatinization temperature⁶. The solubility index of the starch sources varied from 44.20 – 6.53% (**Figure 3**), where the highest water solubility index was reported in Soy. Soy, Chickpea, and Corn showed a significantly ($p < 0.05$) higher solubility index than wheat flour.

According to the literature, the swelling factor of starch is greatly affected by the granule size, protein content, amylose content, and amylopectin branched degree. Smaller granule size leads to higher water absorption due to the more elevated surface area-to-volume ratio²⁴. Therefore, higher water swelling power is expected in starches with smaller granule sizes²⁷. However, such a correlation could not observe in the studied starch sources.

Freeze-thaw stability

Starch is used as an ingredient for producing frozen foods such as sausages, hams, surimi, and frozen batters. During long-term storage, these food products are typically exposed to a series of temperature fluctuations. Therefore, freeze-thaw stability in starch is an important factor in ensuring the textural quality of frozen products ^{7,28}. As shown in **Table 1**, Soy showed the highest syneresis percentage (72.26%), reflecting the lowest freeze-thaw stability. The lowest syneresis percentage was reported in White raw rice (11.48%), followed by Finger millet (15.37%) and Palmyra (17.05%). Wheat is the most commonly used starch source in the bakery industry, where its syneresis percentage was reported as 25.76% in the present study. In this experiment, White raw rice, Finger millet, Palmyra, and White basmati showed significantly ($p < 0.05$) lower syneresis percentage than wheat flour. It indicated higher freeze-thaw stability than Wheat flour and would make them more desirable in industrial purposes.

Dietary fiber composition

Dietary fiber received considerable research interest as it exerts several physiological benefits by reducing the risk of cancer, type 2 diabetes, and cardiovascular disease ^{29,30}. The dietary fiber compositions of the selected starch sources are presented in **Table 2**. The TDF and IDF contents differed significantly ($p < 0.05$) among fifteen starch sources. Soy flour showed the highest TDF, IDF, and SDF content, while wheat flour showed the lowest DF content. TDF and IDF values extended in a broad range: 2.31-38.70% DM, 2.05-32.75%, respectively, where SDF accounted for less than 6% of dry matter. Soybean, Black gram, and Chickpea flour which belong to the legume family, showed significantly ($p < 0.05$) higher DF content than other sources. Out of cereal starch sources, Oats resulted in significantly ($p < 0.05$) higher TDF (17.38%) and IDF (12.48%) content. Water lily seed flour showed moderately higher TDF content (11.34%) and received the highest SDF/TDF ratio, followed by Oats and Kithul. The results were in accordance with the literature

by Awika et al.³¹ that confirmed higher dietary fiber content of legumes compared to cereals. Red raw rice and Red basmati rice flour showed significantly high dietary fiber content than White rice. Refined wheat flour had four times lower TDF content than Whole grain wheat flour. The reported DF content for Wheat flour was fairly agreed with the report of Thadhani et al.³². The lowest dietary fiber content of Wheat flour is mainly attributed to the changes that occur in the milling processing^{33,34}.

Soy, Black gram, and Oats had significantly higher ($p < 0.05$) SDF content than other studied starch sources. SDF is specifically related to the increase in the passage of bile acid, binding toxic compounds, and providing an excellent fermentable substrate to colon microorganisms³⁵. Therefore, Water lily seeds, Oats, and Kithul, like starch sources that have higher SDF/TDF, could exert high prebiotic activity.

Mineral composition

The mineral contents in the studied starch sources are presented in **Table 3**. According to the data, K, Ca and Mg were the most abundant minerals in all studied starch sources. The potassium content varied from 608.6-7862.4 µg/g and magnesium content varied from 148-1099.1 µg/g. Soy had the highest level of K and the second-highest level of Ca, Zn, and Mg. Selected legumes: Soybean, black gram and chickpea contained higher essential and trace elements than other starch sources. Corn had the highest Mg and Zn content whereas Water lily seed had the highest level of Na and Fe. Considering the rice varieties, Red raw rice and Red basmati had significantly higher mineral concentrations than White raw rice and White basmati showing that red rice varieties are nutritionally rich and healthier than the white rice varieties³⁶. The values for the mineral composition in Red rice and White rice fell in line with the results of Jiang et al.³⁷ In this

experiment, Wheat showed the lowest content of K, Mg, Zn, and Mn from the studied starch sources. Results depict the importance of the consumption of legumes which is a good source of minerals compared to other starch sources. These findings would help in developing functional foods and various other value-added products.

Prebiotic activity

Prebiotics are defined as “non-digestible food ingredients that beneficially affect host health by selectively stimulating the growth and activity of one or a limited number of bacteria in the colon”³⁸. The higher number of beneficial bacteria in the colon leads to an increase the nutrient and mineral absorption in the intestine, stimulates the production of short-chain fatty acids, and synthesis of water-soluble vitamins. Thus, there is an emerging trend of using prebiotics for functional food preparation³⁹. The current study focused on evaluating the proliferation ability of probiotic bacteria: *Lactobacillus acidophilus* and *Bifidobacterium animalis* Sub sp. *lactis* in the presence of fifteen different starch sources. The quantitative changes in the bacterial population at the end of the fermentation period are shown in **Figure 4**. For both strains, Water lily seeds resulted the highest bacterial growth enhancement. The media containing Water lily seed, Oats, and White basmati received significantly ($p < 0.05$) higher growth enhancement than all other carbohydrate substrates.

Finding supportive evidence is rare to prove the result obtained for the present study. Studies conducted so far mainly focused on assessing the prebiotic activity of purified oligosaccharides (fructo-oligosaccharides, galacto-oligosaccharides), inulin, lactulose, and resistant starch-like non-digestible compounds extracted from different dietary sources^{40–42}. However, very limited studies have investigated the prebiotic activity using dietary sources without extracting these compounds.

The data from those studies are also often based on one particular substrate or limited to two or three starch substrates⁴³.

Several *in vitro* studies have specifically focused on evaluating the prebiotic effect of Lotus seed. It has been identified that Lotus seed is a rich source of bioactive compounds, water-soluble polysaccharides with a high content of oligosaccharides, and resistant starch⁴⁴. That might be the reason for the higher proliferation effect of probiotic bacteria with the presence of Water lily seeds. Oats received considerable attention in the field of research due to their protective functions against most diet-related non-communicable diseases. This would be due to the presence of β -glucan. Several *in-vitro* studies recommend oats as one of the best sources of β -glucan²⁹. That is not a miracle to depict the high prebiotic activity of Oats. Interestingly water lily seeds resulted in 0.96 log fold higher growth enhancement of *L. acidophilus* and 0.2 log fold higher growth enhancement of *B. animalis* than the Oats as a fermentative substrate.

Although White basmati, Finger millet, and Kithul gained significantly ($p < 0.05$) higher bacterial proliferation than other starch sources, less research interest was received for those starch sources as fermentative substrates. There was no correlation between total dietary fiber content and prebiotic activity in these fifteen starch sources. That might be due to the high variability in the selected botanical source. However, the ratio of soluble dietary fiber content to the total dietary fiber content (SDF/TDF) positively correlated ($r=0.62$) to the prebiotic activity.

Conclusion

The isolated starch from selected botanical sources exhibited variations in granular morphology and size, with a notable difference in amylose content ($p < 0.05$). Among these sources, Kithul, Palmyra, and Finger millet showed significantly higher water swelling capacity and water

absorption index, suggesting their potential as effective binders or stabilizers. White raw rice, Finger millet, and Palmyra showed significantly higher freeze-thaw stability compared to that of wheat, indicating their suitability as ingredients in frozen and cold storage food manufacturing. The results indicate the potential utilization of White raw rice, Palmyra, and Finger millet starch in the food processing industry as alternatives to conventional starch sources.

Moreover, the flours of Soy, Black gram, and Chickpea showed significantly higher ($p < 0.05$) potassium content, along with significantly higher TDF and IDF content. These attributes suggest potential health benefits in the prevention of non-communicable diseases. Water lily seeds and White Basmati rice flour exhibited remarkable prebiotic activity, indicating their potential in the development of functional food with enhanced health benefits.

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Conflict of interest

The authors declare that they have no conflict of interest.

Author contribution

S.M. Sewwandi: Methodology, Formal analysis, Investigating, Data curation, Writing the original draft, visualization; R.T.P. Liyanage: Formal analysis, Investigating, Data curation; R.J. Bangamuwage: Formal analysis, Investigating, Data curation; I. Rathnayake: Formal analysis, Investigating, Data curation; F.A. Deen: Formal analysis, Investigating, Data curation; B.C. Jayawardana: Resources, Writing review, and editing. Ruvini Liyanage: Conceptualization,

Validation, Formal analysis, Resources, Writing review and editing, Supervision, project administration.

References

1. Ludwig DS, Hu FB, Tappy L and Brand-Miller J, Dietary carbohydrates: role of quality and quantity in chronic disease. *Bmj* 361 (2018).
2. Slyper AH, The influence of carbohydrate quality on cardiovascular disease, the metabolic syndrome, type 2 diabetes, and obesity– an overview. *J Pediatr Endocrinol Metab* **26** (7–8): 617–629 (2013).
3. Campos V, Tappy L, Bally L, Sievenpiper JL and Lê KA, Importance of carbohydrate quality: what does it mean and how to measure it? *J Nutr* **152**(5): 1200–1206 (2022).
4. Jayawardena R, Byrne NM, Soares MJ, Katulanda P and Hills AP, Food consumption of Sri Lankan adults: An appraisal of serving characteristics. *Public Health Nutr* **16**(4): 653–658 (2013).
5. Jayatissa RLN, Wickramasinghe WD and Piyasena C, Food Consumption Patterns in Sri Lanka. Hector LKobbakaduwa Agrarian research and training institute (2014).
6. Aprianita A, Purwandari U, Watson B and Vasiljevic T, Physico-chemical properties of flours and starches from selected commercial tubers available in Australia. *Int Food Res J* **16**(4): 507–520 (2009).
7. Bashir K and Aggarwal M, Physicochemical , structural and functional properties of native and irradiated starch: a review. *J Food Sci Technol* **56**(2): 513–23 (2019).
8. Zhu F, Underutilized and unconventional starches: Why should we care? *Trends Food Sci*

Technol. **100**:363–373 (2020).

9. Deng M, Reddy CK and Xu B, Morphological, physico-chemical and functional properties of underutilized starches in China. *Int J Biol Macromol* **158**: 648–655 (2020).
10. Slavin J, Fiber and prebiotics: Mechanisms and health benefits. *Nutrients* **5**(4): 1417–1435 (2013).
11. Noor F, Rahman MJ, Mohomud MS, Akter MS, Talukder MAI and Ahmed M, Physicochemical Properties of Flour and Extraction of Starch from Jackfruit Seed. *Int J Nutr Food Sci* **3**(4): 347 (2014).
12. Charoenrein S, Tatirat O and Muadklay J, Use of centrifugation-filtration for determination of syneresis in freeze-thaw starch gels. *Carbohydr Polym* **73**(1): 143–147 (2008).
13. Wani IA, Sogi DS, Wani AA, Gill BS and Shivhare US, Physico-chemical properties of starches from Indian kidney bean (*Phaseolus vulgaris*) cultivars. *Int J Food Sci Technol* **45**(10): 2176–2185 (2010).
14. Prosky L, Asp NG, Schweizer TF, Devaries JW, Furfa I and Lee SC, determination of soluble dietary fiber in foods and food products: collaborative study. *JAOAC Int* **77**(3): 690–4 (1994).
15. Sarikurkcu C, Copur M, Yildiz D and Akata I, Metal concentration of wild edible mushrooms in Soguksu National Park in Turkey. *Food Chem* **128**(3): 731–734 (2011).
16. Sayar S, Jannink JL and White PJ, Digestion residues of typical and high- β -glucan oat flours provide substrates for in vitro fermentation. *J Agric Food Chem* **55**(13): 5306–5311

(2007).

17. Huebner J, Wehling RL and Hutkins RW, Functional activity of commercial prebiotics. *Int Dairy J* **17**(7):770–5 (2007).
18. Singh J, Colussi R, McCarthy OJ and Kaur L, Potato Starch and Its Modification. *In Advance in potato chemistry and technology* 195–247 (2016).
19. Chakraborty I, Pallen S, Shetty Y, Roy N and Mazumder N, Advanced microscopy techniques for revealing molecular structure of starch granules. *Biophys Rev* **12**(1): 105–122 (2020).
20. Verma VC, Kumar A, Zaidi MGH, Verma AK, Jaiswal JP, Singh DK, Singh A and Agrawal S, Starch isolation from different cereals with variable amylose/amylopectin ratio and its morphological study using SEM and FT-IR. *Int J Curr Microbiol Appl Sci* **7**(10): 211–228 (2018).
21. Suwannaporn P, Pitiphunpong S and Champangern S, Classification of rice amylose content by discriminant analysis of physicochemical properties. *Starch/Starke*. **59** (3-4):171–177 (2007).
22. Stevenson DG, Doorenbos RK, Jane J and Inglett GE, Structures and functional properties of starch from seeds of three soybean (*Glycine max* (L.) Merr.) Varieties. *Starch/Starke* **58**(10): 509–519 (2006).
23. Singh N, Kaur M, Sandhu KS and Guraya HS, Physicochemical, thermal, morphological and pasting properties of starches from some indian black gram (*Phaseolus mungo* L.) Cultivars. *Starch/Starke* **56**: 535–544 (2004).

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24. Soh HN, Sissons MJ and Turner MA, Effect of starch granule size distribution and elevated amylose content on durum dough rheology and spaghetti cooking quality. *Cereal Chem* **83**(5): 513–519 (2006).
 25. Jayawardana SAS, Samarasekera JKRR, Hettiarachchi GHCM, Gooneratne J, Mazumdar SD and Banerjee R, Dietary fibers, starch fractions and nutritional composition of finger millet varieties cultivated in Sri Lanka. *J Food Compos Anal* **82**:103249 (2019).
 26. Chibbar RN, Ambigaipalan P and Hoover R, Molecular diversity in pulse seed starch and complex carbohydrates and its role in human nutrition and health. *Cereal Chem* **87**(4): 342–352 (2010).
 27. Sasaki T and Matsuki J, Effect of wheat starch structure on swelling power. *Cereal Chem* **75**(4):525–529 (1998).
 28. Srichuwong S, Isono N, Jiang H, Mishima T and Hisamatsu M, Freeze – thaw stability of starches from different botanical sources: Correlation with structural features, *Carbohydr Polym* **87**(2):1275–1279 (2012).
 29. Dodevska MS, Djordjevic BI, Sobajic SS, Miletic ID, Djordjevic PB and Dimitrijevic-Sreckovic VS, Characterisation of dietary fibre components in cereals and legumes used in Serbian diet. *Food Chem* **141**(3): 1624–1629 (2013).
 30. Lattimer JM and Haub MD, Effects of dietary fiber and its components on metabolic health. *Nutrients* **2**(12):1266–1289 (2010).
 31. Awika JM, Rose DJ and Simsek S, Complementary effects of cereal and pulse polyphenols and dietary fiber on chronic inflammation and gut health. *Food and Fun* **9**(3):

1389–1409 (2018).

32. Thadhani VM, Jansz ER and Peiris H. The digestible carbohydrate and dietary fibre contents of common sri lankan plant foodstuffs. *J Natl Sci Found Sri Lanka* **28**(4):253–64 (2000).
33. Slavin JL, Jacobs JR and Marquant L, Whole grain consumption and chronic disease: potential mechanisms. *FASEB J* **10**(3): 37–41 (1996).
34. Oghbaei M and Prakash J, Effect of primary processing of cereals and legumes on its nutritional quality: A comprehensive review. *Cogent Food Agric* **2**(1):1–14 (2016).
35. Mudgil D and Barak S, Composition, properties and health benefits of indigestible carbohydrate polymers as dietary fiber: A review. *Int J Biol Macromol* **61**:1–6 (2013).
36. Rathna Priya TS, Eliazar Nelson ARL, Ravichandran K and Antony U, Nutritional and functional properties of coloured rice varieties of South India: a review. *J Ethn Foods* **6**(1):1–11 (2019).
37. Jiang SL, Wu JG, Thang NB, Feng Y, Yang XE and Shi CH, Genotypic variation of mineral elements contents in rice (*Oryza sativa* L.). *Eur Food Res Technol.* **228**:115–22 (2008).
38. Gibson GR and Roberfroid MB, Dietary Modulation of the Human Colonic Microbiota: Introducing the Concept of Prebiotics. *J Nutr* **125**(6):1401–1412 (1995).
39. Wang Y. Prebiotics: Present and future in food science and technology. *Food Res Int.* **42**(1): 8–12 (2009).
40. Cardelle-Cobas A, Fernández M, Salazar N, Martínez-Villaluenga C, Villamiel M, Ruas-

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Madiedo P and de los Reyes-Gavilan CG, Bifidogenic effect and stimulation of short chain fatty acid production in human faecal slurry cultures by oligosaccharides derived from lactose and lactulose. *J Dairy Res* **76**(3): 317–25 (2009).

41. Rodriguez-Colinas B, Kolida S, Baran M, Ballesteros AO, Rastall RA and Plou FJ, Analysis of fermentation selectivity of purified galacto-oligosaccharides by in vitro human faecal fermentation. *Appl Microbiol Biotechnol* **97**(13):5743–52 (2013).
42. Rycroft CE, Jones MR, Gibson GR and Rastall RA. A comparative in vitro evaluation of the fermentation properties of prebiotic oligosaccharides. *J Appl Microbiol* **91**(5):878–887 (2001).
43. Gullón P, Gullón B, Tavaría F, Vasconcelos M and Gomes AM, In vitro fermentation of lupin seeds (*Lupinus albus*) and broad beans (*Vicia faba*): Dynamic modulation of the intestinal microbiota and metabolomic output. *Food Funct* **6**(10): 3316–3322 (2015).
44. Tian Y, Zheng B, Chen C and Zheng Y, Ultrasound-assisted extraction, preliminary characterization, and antioxidant activity of a novel water-soluble polysaccharide from lotus (*Nelumbo nucifera* Gaertn.) Seeds. *Sep Sci Technol*. **47**(16): 2408–2416 (2012).

Table 1: Syneresis% and amylose content in commonly consumed carbohydrate sources

Starch Sample	Syneresis (%)	Amylose (%)
Soybean	72.26±2.08 ^a	17.22±0.41 ^k
Black gram	24.25±1.15 ^g	32.95±0.86 ^{bc}
Chickpea	38.66±1.15 ^{cd}	27.09±0.32 ^{fg}
Oats	40.45±3.34 ^b	25.41±2.09 ⁱ
Finger millet	15.37±0.52 ^{hi}	27.62±0.93 ^{ef}
Corn	36.84±1.60 ^c	31.83±0.74 ^{cd}
Palmyra	17.05±1.00 ^h	36.12±0.92 ^a
Water lily seeds	23.53±1.23 ^g	30.19±1.48 ^d
Kithul	29.35±1.24 ^{ef}	25.39±0.65 ^{hi}
White Raw Rice	11.48±0.81 ⁱ	26.07±0.02 ^{gh}
Red Raw Rice	43.38±1.10 ^b	30.95±2.53 ^e
White Basmati	17.61±0.48 ^{hi}	24.23±0.98 ^{hi}
Red Basmati	23.54±1.95 ^g	19.29±0.21 ^j
Whole grain wheat Flour	31.05±0.97 ^{de}	33.45±1.10 ^b
Wheat	25.76±4.32 ^{fg}	31.21±0.49 ^{cd}

Values are mean ± standard deviation. n=2

Mean with different superscript letters within a column are significantly different ($p < 0.05$)

Table 2: Dietary fiber content (DF) of carbohydrate sources (dry matter basis)

Starch source	TDF content (%)	IDF content (%)	SDF content (%)	SDF/TDF content
Soybean	38.70 ± 0.24 ^a	32.75 ± 0.16 ^a	5.95 ± 0.07 ^a	0.15
Black gram	33.05 ± 0.13 ^b	27.44 ± 0.10 ^b	5.61 ± 0.03 ^b	0.17
Chickpea	22.91 ± 0.05 ^c	18.98 ± 0.07 ^c	3.93 ± 0.02 ^d	0.17
Oats	17.38 ± 0.14 ^d	12.48 ± 0.06 ^d	4.90 ± 0.20 ^c	0.28
Finger millet	15.51 ± 0.09 ^e	11.74 ± 0.18 ^e	3.12 ± 0.02 ^f	0.21
Corn	15.34 ± 0.32 ^f	13.41 ± 0.23 ^f	1.93 ± 0.09 ^g	0.14
Palmyra	11.82 ± 0.05 ^g	10.25 ± 0.15 ^g	1.57 ± 0.11 ^h	0.13
Water lily seeds	11.34 ± 0.11 ^h	8.02 ± 0.23 ^h	3.32 ± 0.12 ^e	0.29
Kithul	3.66 ± 0.15 ⁱ	2.73 ± 0.11 ⁱ	0.93 ± 0.03 ^{ij}	0.25
White raw rice	2.49 ± 0.10 ^m	1.93 ± 0.06 ⁿ	0.56 ± 0.04 ^j	0.22
Red raw rice	7.36 ± 0.18 ^j	6.39 ± 0.10 ^j	0.97 ± 0.07 ^{ij}	0.13
White Basmati	4.90 ± 0.13 ^k	3.82 ± 0.22 ^k	1.08 ± 0.08 ⁱ	0.22
Red Basmati	7.66 ± 0.19 ^j	7.31 ± 0.04 ⁱ	0.35 ± 0.15 ^k	0.04
Atta	8.48 ± 0.18 ⁱ	6.42 ± 0.07 ^j	2.06 ± 0.11 ^g	0.24
Wheat flour	2.31 ± 0.13 ^m	2.06 ± 0.09 ^m	0.25 ± 0.03 ^k	0.11

Values are mean ± standard deviation. n=2

Mean with different superscript letters within a column are significantly different ($p < 0.05$)

Table 3: Mineral composition of commonly available carbohydrate sources

Starch source	K	Ca	Mg	Na	Fe	Zn	Mn
Soybean	7862.4±86.1 ^a	889.8±0.8 ^b	992.0±32.9 ^b	10.7±0.5 ^{hi}	35.6±0.4 ^d	20.7±0.16 ^b	13.0±0.1 ^c
Black gram	5806.3±50.7 ^b	312.47±8.6 ^{de}	807.7±58.6 ^c	24.3±0.2 ^d	23.2±0.5 ^f	15.6±0.2 ^c	7.6±0.05 ^g
Chickpea	4828.1±80.1 ^c	267.5±69 ^{ef}	452.81±9.6 ^e	32.1±0.9 ^c	65.0±1.6 ^b	14.3±0.2 ^d	7.01±0.05 ⁱ
Oats	2934.4±19.7 ^f	257.5±26.1 ^{ef}	183.14±3.5 ^{fgh}	18.7±1.1 ^{ef}	7.6±0.2 ^{ijk}	6.5±0.1 ⁱ	7.4±0.1 ^h
Finger millet	1836.2±51.1 ^h	729.1±34.2 ^c	394.4±7.5 ^e	18.5±0.2 ^{ef}	10.2±0.4 ^{hi}	5.6±0.02 ^j	29.1±0.03 ^a
Corn	4294.4±7.6 ^d	125.5±5.4 ^{ghi}	1099.1±72.8 ^a	11.9±0.3 ^{hi}	28.6±0.9 ^e	25.1±0.07 ^a	5.7±0.1 ^j
Palmyra	3591.8±58.2 ^c	166.7±11.6 ^{gh}	162.6±3.22 ^{gh}	59.6±4.3 ^b	10.1±0.68 ^{hij}	4.6±0.0 ^k	2.2±0.02 ⁿ
White waterlily	1531.7±16.0 ⁱ	356.9±5.57 ^d	276.3±7.3 ^f	79.1±2.3 ^a	119.6±3.74 ^a	8.4±0.02 ^h	11.81±0.04 ^d
Kithul	1610.5±30.5 ⁱ	1015.6±34.4 ^a	600.2±44.5 ^d	23.6±0.3 ^d	59.2±1.15 ^c	11.2±0.3 ^f	9.3±0.2 ^f
White raw rice	653.4±24.6 ^k	42.8±2.3 ^j	250.8±2.11 ^{fg}	8.5±0.5 ⁱ	4.4±0.2 ^k	5.9±0.12 ^j	5.08±0.11 ^k
Red raw rice	1365.2±27.2 ^j	75.19±4.58 ^{ij}	666.93±4.0 ^d	13.7±0.5 ^{gh}	12.3±0.6 ^h	9.5±0.02 ^g	11.3±0.03 ^e
White basmati	1325.7±8.64 ^j	59.1±1.9 ^{ij}	691.5±7.1 ^d	16.9±0.8 ^{fg}	6.7±0.3 ^{jk}	5.65±0.2 ^j	2.6±0.1 ^m
Red basmati	2473.4±26.2 ^g	122.72±4.87 ^{ghi}	1034.4±60.4 ^{ab}	22.23±0.3 ^{de}	16.4±0.2 ^g	13.5±0.01 ^e	18.79±0.2 ^b
Atta	1776.8±41.1 ^h	196.6±11.5 ^{fg}	445.21±14 ^e	17.0±0.5 ^{fg}	18.7±0.5 ^g	10.8±0.1 ^f	11.12±0.4 ^d
Wheat flour	608.6±13.57 ^k	118.4±9.9 ^{hi}	148.3±7.7 ^h	9.5±0.2 ^{hi}	7.5±0.2 ^{ijk}	4.7±0.02 ^k	3.1±0.13 ^l

Values are mean ± standard deviation. n=2

Mean with different superscript letters within a column are significantly different ($p < 0.05$)

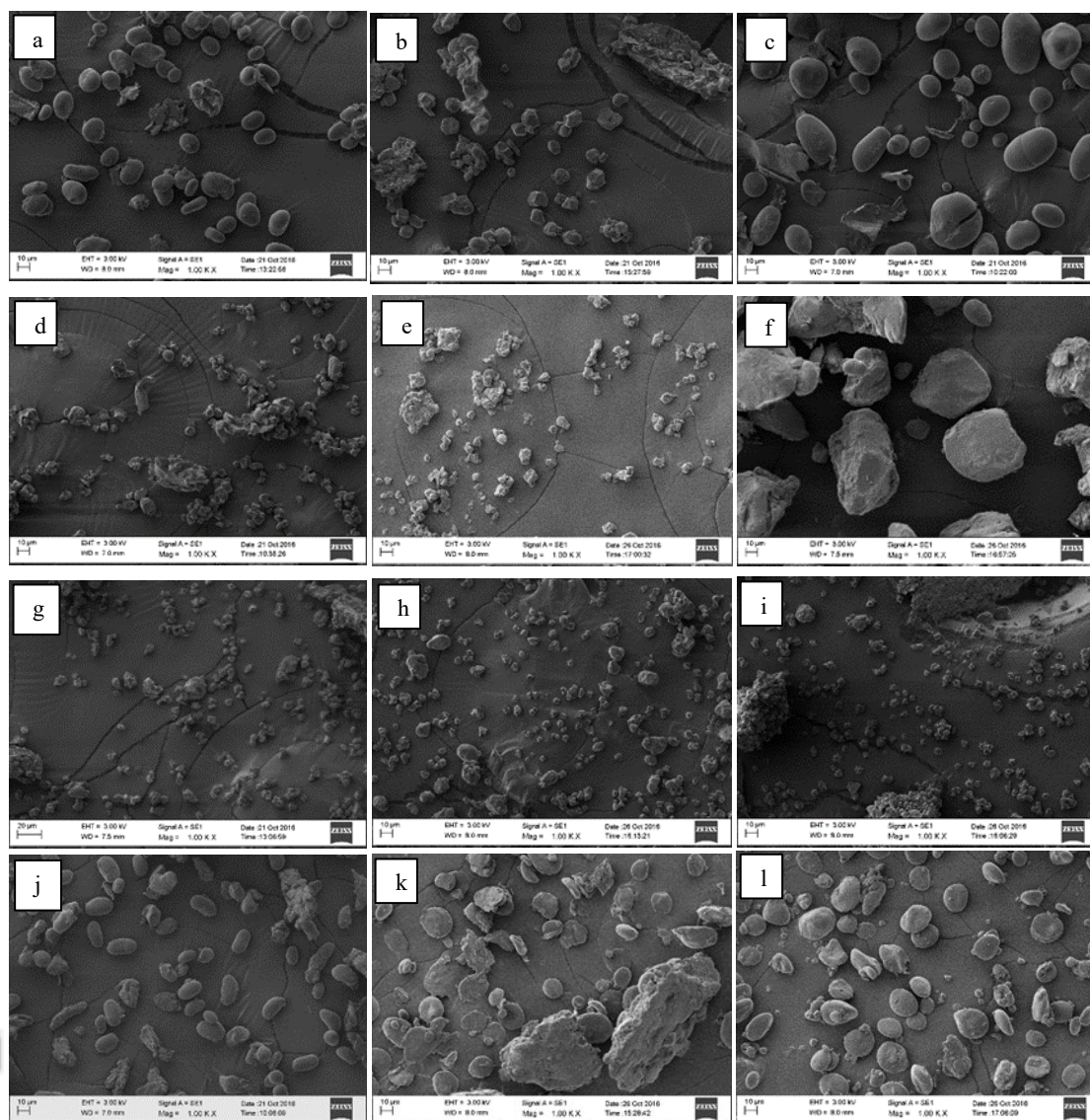


Figure 1: SEM images of starch isolated from (a) Chickpea (b) Corn (c) Kithul (d) Finger millet (e) Oats (f) Palmyra (g) Red raw rice (h) White raw rice (i) White basmati rice (j) Black gram (k) Whole grain wheat flour (l)Wheat flour

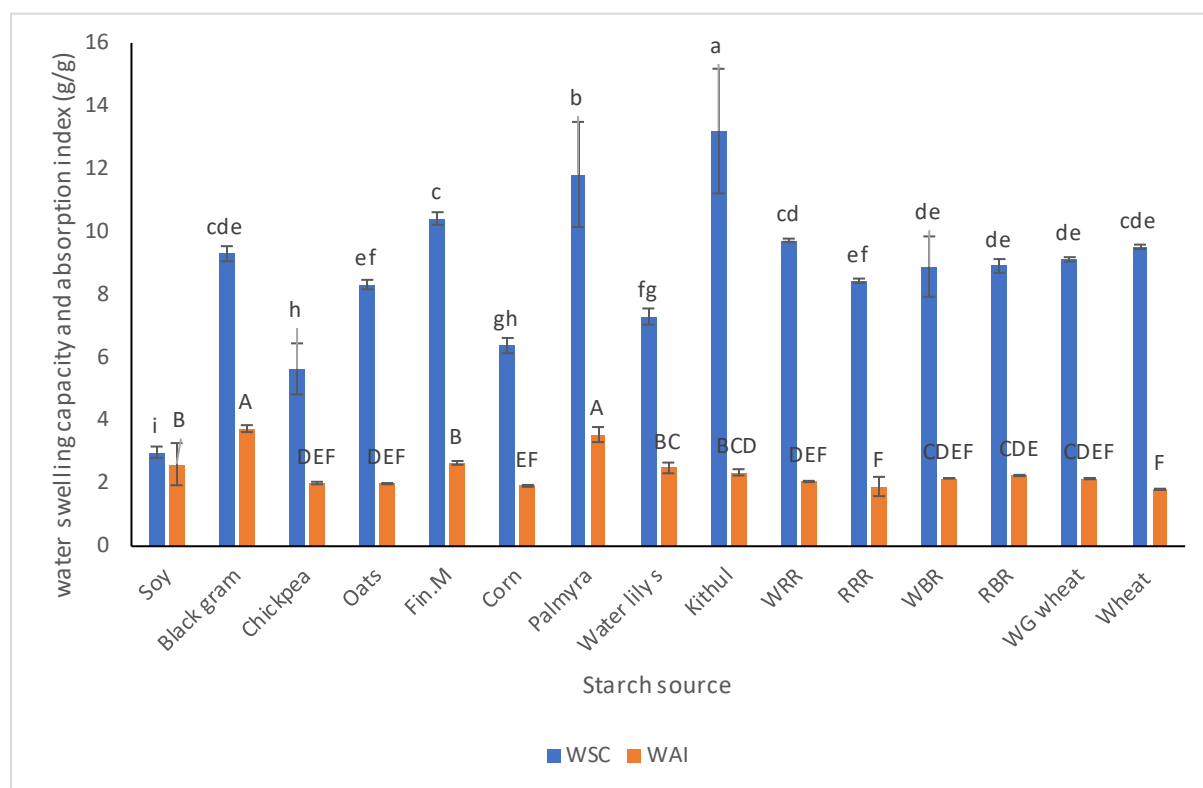


Figure 2: Water swelling capacity (WSC) and water absorption index (WAI) of starch sources

Values are given as means of three replicates \pm SD. Mean difference in WSC and WAI indicate in lower case and upper-case letters respectively, means with different superscript letters are significantly different ($p < 0.05$). Fin. M: Finger millet, WRR: White raw rice, RRR: Red raw rice, WBR: White basmati rice, RBR: Red basmati rice, WG wheat: Whole grain wheat flour

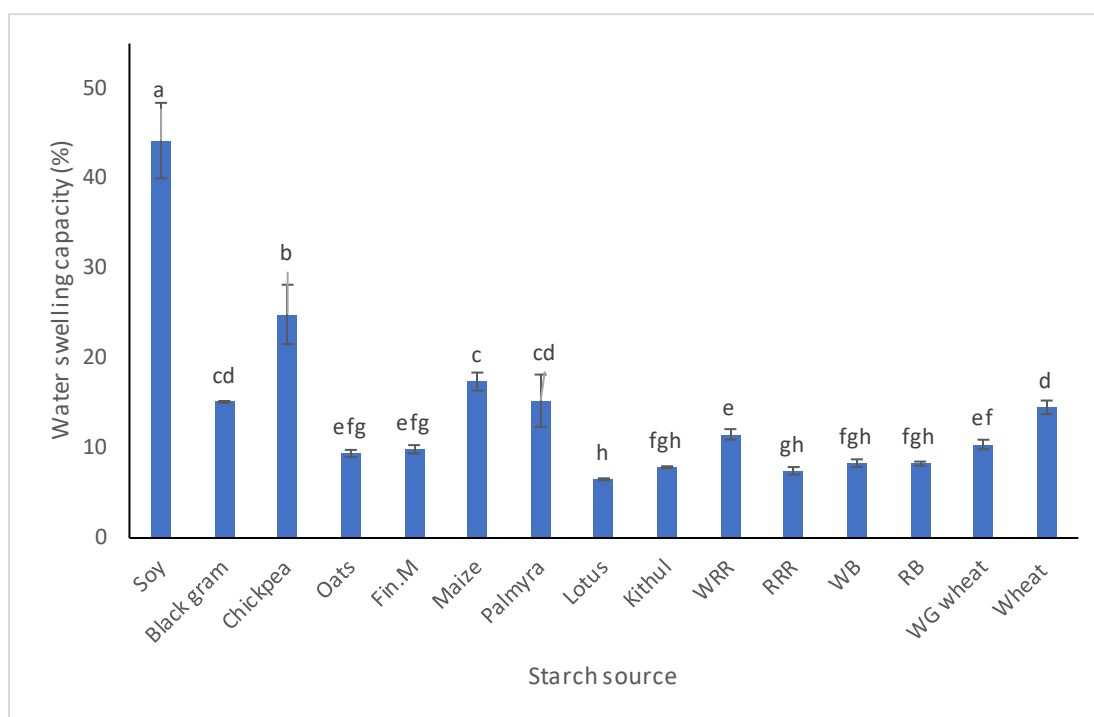


Figure 3: Watersolubility index of starch sources

Values are given as means of three replicates \pm SD. Means with different superscript letters are significantly different ($p < 0.05$). Fin. M: Finger millet, WRR: White raw rice, RRR: Red raw rice, WBR: White basmati rice, RBR: Red basmati rice, WG wheat: Whole grain wheat flour

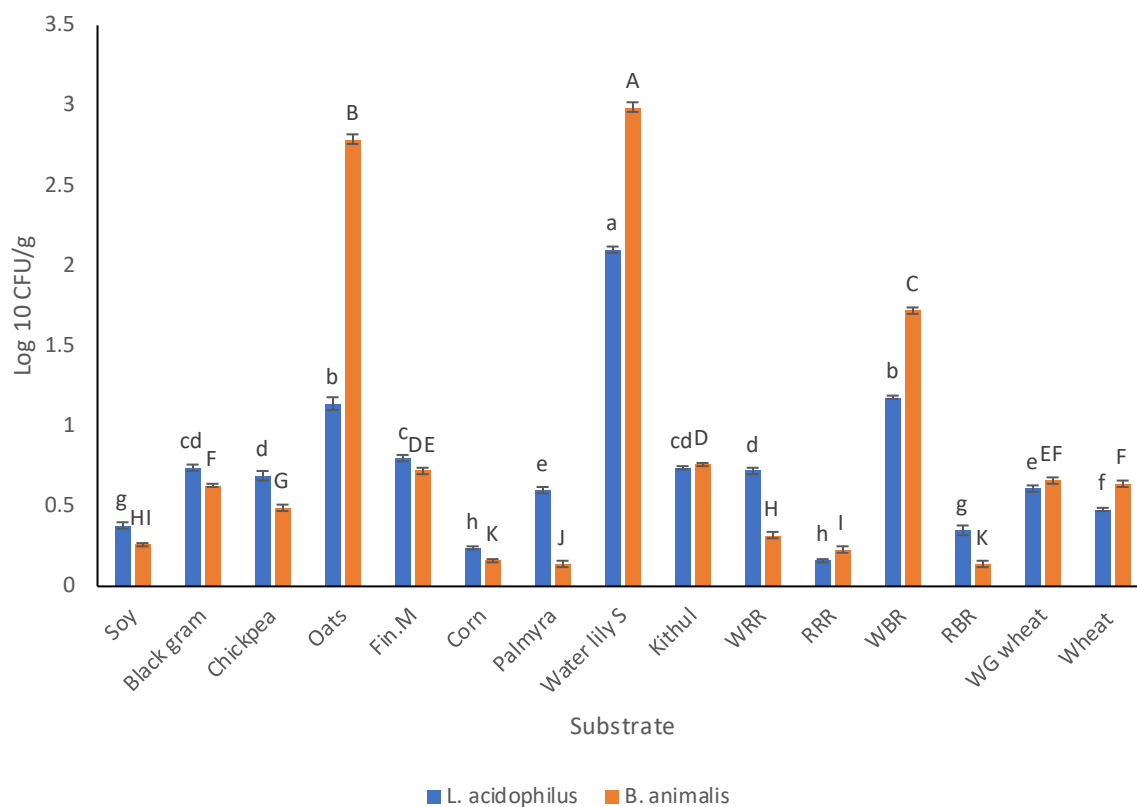


Figure 4: Effect of starch substrate on the proliferation of *Lactobacillus acidophilus* and *Bifidobacterium animalis* subsp. Lactis

Values are given as means of three replicates \pm SD. Means with different superscript letters are significantly different ($p < 0.05$). Mean difference between bacterial count in *L. acidophilus* and *B. animalis* are expressed in lower case and uppercase letters respectively. Fin. M: Finger millet, WRR: White raw rice, RRR: Red raw rice, WBR: White basmati rice, RBR: Red basmati rice, WG wheat: Whole grain wheat flour