Future Postharvest and Food

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ORIGINAL PAPER OPEN ACCESS

Standardization of Microwave Heating Process Parameters for Extraction of Galactooligosaccharides (GOS) From Ricebean Flour

Bharat Bhushan | Rakesh Kumar Raigar

Department of Processing and Food Engineering, College of Agricultural Engineering and Post-Harvest Technology, Central Agricultural University, Imphal, Manipur, India

Correspondence: Rakesh Kumar Rigar (rakeshiitkgp07@gmail.com)

Received: 10 April 2025 | **Revised:** 16 July 2025 | **Accepted:** 1 August 2025

Funding: The authors received no specific funding for this work.

Keywords: antioxidant activity | galctooligosaccharides | microwave extraction | ricebean | total phenolic content

ABSTRACT

Ricebean (*Vigna umbellata*) is a versatile, nutritious crop cultivated in hilly regions, offering significant nutritional contents and serving as a vital livelihood source for the Himalayan population. It has ample amount of nutritional characteristics especially galctooligosaccharides (GOS) which possess prebiotic properties. Therefore, the study was aimed to extract the GOS from ricebean using microwave heating technique. The full factorial design (27 experiments) was applied to optimize the microwave heating process parameters (microwave power: 240–640 W, time: 3–9 min, water to flour ratio: 14:1 to 20:1 mL/g), and its linear and interaction effects of process conditions were evaluated on the GOS yield, total phenolic content (TPC), antioxidant activity (AC) and pH. The GOS, TPC, and AC were significantly ($p < 0.05$) influenced by all the process parameters. Microwave power had significant impact on GOS with higher yield 2.58 g/L. In optimization, the best process conditions were obtained at 3 min extraction time, 400 W power, and 14:1 mL/g water to flour ratio with higher desirability (0.77) for maximum GOS yield, TPC, and AC. Moreover, the microwave heating as an ecofriendly technique had the potential to be applied to underutilized pulses (ricebean).

1 | Introduction

Ricebean, a leguminous crop, is chiefly grown in hilly parts of India (Himachal Pradesh, Sikkim, Meghalaya, Uttarakhand, Assam, Eastern Bihar, Manipur, Arunachal Pradesh, Nagaland, and Mizoram) during Kharif season (Eltayeb et al. 2011). The ricebean is known as masyum dhal in the local population of Sikkim and is widely consumed as a curry with rice. The nutritional value of ricebean with respect to protein (22.56%–25.97%) and lipid (1.5%–3%) is relatively close to other legumes such as green gram and Bengal gram (Katoch et al. 2023). Apart from the content of protein and lipids, the quality of protein (digestibility: 53%–57%) and high levels of unsaturated fatty acids were also found. Ricebean also has certain beneficial compounds in the form of carbohydrates (oligosaccharides), which can be utilized as prebiotics or functional food ingredients (Katoch 2013).

Most frequently, oligosaccharides are defined as short-chain carbohydrates having monosaccharides in the range of 2–10 unit (BeMiller 2018). According to physicochemical characteristics, oligosaccharides are less sweet than sucrose, with their sweetness ranging from 30% to 60% of sucrose. Oligosaccharides are soluble in water and are ideal as a less bulky flavor enhancer for people with diabetes, heart disease, or thrombosis (D. L. Su et al. 2019). The various types of oligosaccharides are present in

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different types of foods, such as fructo-oligosaccharides (FOS) in fruits and vegetables (asparagus, sugar beet, garlic, chicory, onion, bananas, and tomatoes), galacto-oligosaccharides in legumes, nuts, soybeans, soy products, and peas, and β-Glucans in oats and barley, etc. (Gyawali et al. 2019). Most importantly, as compared with other oligosaccharides such as fructo-oligosaccharides, the raffinose family oligosaccharides are more effective in increasing the counts of *Bifidobacterium* while generating the least gases (Fernando et al. 2010).

Raffinose family oligosaccharides also help in increasing the growth of lactobacilli species (Kunová et al. 2011). Therefore, raffinose family oligosaccharides are considered superior prebiotics as compared with other oligosaccharides (Van den Ende 2013).

To incorporate oligosaccharides into the food product, extraction is an essential process. Several methods are widely used for extraction of functional components from cereals and pulses such as soaking, conventional cooking, and enzymatic hydrolysis. Enzymatic hydrolysis of galactooligosaccharides is achieved by the α-galactosidase enzyme. This enzyme breaks the glycosidic bond present between sucrose and galactose monomers, which results in the hydrolysis of galactooligosaccharides (de Menezes et al. 2009). Enzymatic hydrolysis is the best mechanism used so far to produce oligosaccharides in higher amounts (Barreteau et al. 2006). Although complete extraction of galactooligosaccharides was reported using soluble enzymes, the sole use of soluble enzymes leads to several disadvantages such as the high cost of the operation, contamination by proteins, microbes, and monosaccharides, and the requirement for strict control over the reaction (de Moura et al. 2015). Traditional heating is the classical method used to cook legumes before consumption and also used to extract the anti-nutrients such as galactooligosaccharides. But the traditional heating is a time-consuming and tedious process as compared with advanced extraction techniques such as microwave heating (Carrero-Carralero et al. 2018).

Microwave heating is a green process and is widely used in the food processing industry. The electromagnetic spectrum frequency band from 0.3 to 300 GHz is represented by microwaves. The heating process of microwaves depends on the interaction of microwaves and food materials. The interaction of heat generation is governed by ionic collisions and rotations of dipoles. Unlike traditional cooking methods, microwaves penetrate food products and help in improving extraction yields, the volume of solvent, and reducing the time of extraction. Additionally, due to its simple operation and low cost, it provides a wide application to the extraction of various types of carbohydrates (Mena-García et al. 2019). Microwave heating mechanism has been reported to be useful for the extraction of polysaccharides from orange peel, *Ulva prolifera*, mulberry leaves, and jujube, respectively (Rostami and Gharibzahedi 2016; D. L. Su et al. 2019; Thirugnanasambandham et al. 2015; Zhang et al. 2019). However, many literature reported the extraction of different functional components by using soaking, enzymatic treatment with hot water, and studies are scare on the microwave extraction techniques for the underutilized legume, that is, ricebean (Carrero-Carralero et al. 2018).

Therefore, this study focused on evaluating the suitability of microwave extraction process parameters, that is, microwave power, time and water-flour ratio, and optimizing extraction of GOS in an underutilized legume (ricebean).

2 | Materials and Methods

2.1 | Plant Material and Chemicals

Initially, green variety ricebean seeds were manually cleaned for the removal of materials such as dust, stone, and chaff. After cleaning, the seeds were stored in metal bins at ambient temperature. The Raffinose/D-Galactose Megazyme assay kit (K-RAFGA) was procured from the Megaenzyme, and the necessary lab chemicals (Folin & ciocalteu's phenol reagent, gallic acid monohydrate, sodium carbonate anhydrous, DPPH (2, 2-diphenyl-1-picrylhydrazyl), ethanol, sulfuric acid, potassium sulfate, copper sulfate, sodium hydroxide, boric acid and phenolphthalein indicator) were procured from authentic manufacturer and suppliers.

2.2 | Experimental Design

The three-level (3^k) of customized full factorial design (FFD) was adopted to obtain the different experimental combinations ($3 \times 3 \times 3 = 27$ experiments) of the microwave heated extraction process. The FFD provides all the possible combinations of independent variables and offers the precise results of the interaction between variables without losing information. The model produced from a three-level customized FFD design was used to probe the effect of three independent variables: microwave power (X_1), water to flour ratio (X_2), and heating time (X_3) on galactooligosaccharides yield (Y_1), total phenolic content (Y_2), antioxidant activity (Y_3) and pH (Y_4). Based on preliminary trials, the range of independent variables were chosen with their coded values is given in Table 1 (Setyaningsih et al. 2022).

2.3 | Microwave Extraction Process

The microwave heating method for extraction of galactooligosaccharides from ricebeans was carried out using the method described by Carrero-Carralero et al. (2018). In this method, cleaned green variety of ricebean seeds were ground in the food processor (Model FP 2663, Usha) to make flour (less than 150 μm) or to reduce the size of the seed. The flour was mixed with demineralized water as per the required ratios which are presented in Table 1. The obtained mixture of water

TABLE 1 | Selected process parameters with coded levels used for customized full factorial design.

Independent variables	Coded levels		
	−1	0	+1
X_1: Microwave power (W)	240	400	640
X_2: Heating time (minutes)	3	6	9
X_3: Water to flour ratio (mL/g)	14:1	17:1	20:1

and flour was heated in a microwave oven (Model: 20DGLx, Kenstar) according to experimental plan. After heating, the water and flour mixture was allowed to cool down to room temperature of 25°C. The water and flour mixture was poured into centrifuge tubes and centrifuged at 5000 rpm for 10 min in a centrifuge (Model: 3K30, Sigma). After centrifugation, the supernatants were filtered using the Whatman filter paper no.1 to obtain oligosaccharide water extract. The oligosaccharide water extracts were filled in centrifuge tubes and stored in cold storage at −20°C for further experiments.

2.4 | Analysis of Responses

2.4.1 | Galactooligosaccharides Yield

The yield of galactooligosaccharides in microwave extracted ricebean extract was evaluated using the Megazyme Raffinose/D-Galactose Kit (Megazyme), which is an enzyme-based UV absorption method. The purification of extracts was carried out using the method described by Ruiz-Aceituno et al. (2016). Accordingly, extracts were mixed with 1% yeast (w/v) and kept for 8 h at room temperature. The yeast converts the reducing sugar to carbon dioxide and ethanol. After that, the extracts were centrifuged at 5000 rpm for 10 min to remove yeast. Briefly, 0.20 mL of clarified oligosaccharide extract was poured into cuvette using a pipette and 0.10 mL of α-galactosidase reagent was added. The mixture was gently swirled and incubated for 20 min at 25°C. After incubation 2 mL, 0.10 mL, and 0.20 mL of demineralized water, NAD+, and buffer having sodium azide (pH 8.6), respectively, were added. The absorbance at a wavelength of 340 nm was measured in a spectrophotometer (Model: UV-2600, Shimadzu) against distilled water as a blank. The quantity of galactooligosaccharides (the type of oligosaccharide present in legumes) and free D-galactose was measured by the procedure described in the manual provided with the assay kit (Vinjamoori et al. 2004). The demineralized water was used as blank solution. Determinations were measured in triplicate. Results were expressed as g/L.

2.4.2 | Total Phenolic Content (TPC)

The concentration of total phenols in ricebean oligosaccharide water extract was examined by Folin–Ciocalteu colorimetric method as explained by Kupina et al. (2019). In brief, 1 mL of ricebean oligosaccharide water extract was poured into a glass test tube containing 15 mL of demineralized water and 1 mL of Folin–Ciocalteu phenol reagent. The contents of the test tube were mixed by gentle swirling and kept for 7 min at room temperature. After 7 min, 3 mL sodium carbonate solution (Na_2CO_3, 200 g/L) was added to the test tube. The test tube was stored in an incubator at 30°C for 2 h. After two hours, a blue-colored solution was formed and the intensity of blue color was measured by spectrophotometer (UV-2600, Shimadzu) with a wavelength adjusted at 765 nm. The TPC was calculated by using the standard calibration curve and reported in mg GAE/g of samples.

2.4.3 | Antioxidant Activity and pH

The antioxidant assay was performed by adopting DPPH (2, 2-diphenyl-1-picrylhydrazyl) radical scavenging activity method as described by Maurya and Said (2014). The DPPH radical method is most widely used to determine the antioxidants of various natural products. The purple color of the DPPH radical will become discolored in the presence of antioxidants. The absorbance of discoloration was measured using spectrophotometer at 517 nm wavelength. The antioxidant of ricebean oligosaccharides extract was presented in %.

The pH of different oligosaccharide water extracts of different combinations of experiments was estimated using the pH meter (Model: NM-MPH-30B) and average value was noted down from the digital display of the machine. The pH meter was calibrated before conducting the experiments using the standard methodology.

2.5 | Optimization and Validation

For ANOVA analysis of independent parameters concerning the effect on responses (galactooligosaccharides yield, total phenolic content, antioxidant activity, and pH) were analyzed and performed in Design expert software v11.1.2.0 64 – bit (Stat-Ease Inc., Minneapolis, MN, USA). The response produced by each experiment was evaluated by the quadratic model (Equation 1) which was obtained by multiple factorial regression analysis.

$$Y_i = b_o + b_1A + b_2B + b_3C + b_{11}A^2 + b_{22}B^2 + b_{33}C^2 + b_{12}AB + b_{23}BC + b_{13}AC, \quad (1)$$

where Y_i = dependent variable or response; b_o = arithmetic mean response of 27 runs, b_i = estimated regression coefficients; A, B, and C = main effects exhibiting the mean result of changing one factor at a time from the minimum value to a maximum value; AB, AC, BC, ABC = interactions terms; and A^2, B^2, and C^2 = polynomial terms to check the nonlinearity.

The optimization of extraction conditions and validation of the optimized results were carried out accordingly (Raigar et al. 2017). To optimize the extraction conditions of microwave heating methods with the aim of achieving the highest extraction of galactooligosaccharides, maximum total phenolic content, and antioxidant activity, numerical optimization was applied using desirability function methodology (Equation 2). For optimization, the software facilitates to set the desirable conditions or "goal" with respect to independent variables as well as response "in range," "maximize," "minimize" or "target value." The extraction combination having highest desirability was taken as the optimized results. To validate the adequacy of the developed model, triplicate trials were performed using optimized results and compared with the software predicted values. Validation was statistically supported by calculating absolute residual error (% ARE) using Equation (3). The lower

value of ARE is desirable for the justification of the use of the optimized results.

$$Y_D = \left(yd_1^{r_1} \times yd_2^{r_2} \times yd_3^{r_3} \times yd_4^{r_4} \times yd_5^{r_5} \times yd_6^{r_6}\right)^{\frac{1}{(r_1+r_2+r_3+r_4+r_5+r_6)}}, \quad (2)$$

where Y_D: desirability function, yd_i: desirability index, and r_i: different constraints.

$$ARE\ (\%) = \frac{\text{Experimental value} - \text{Predicted value}}{\text{Experimental value}} \times 100. \quad (3)$$

2.6 | Statistical Analysis

Statistical analysis was performed using the Design expert software v11.1.2.0 64—bit (Stat-Ease Inc., Minneapolis, MN, USA). All experiments were performed in triplicate, and the results obtained were expressed as mean ± SD. The data were analyzed by ANOVA ($p < 0.05$).

3 | Results and Discussion

3.1 | Effect of Extraction Conditions on Galactooligosaccharides Yield

The obtained experimental data are presented in Table S1. The obtained experimental data was analyzed by using the design expert software and developed models. The predicted coefficient of the polynomial regression equations, linear, interaction, and quadratic terms of microwave power of the predicted quadratic model were tested for adequacy and fitness by ANOVA (analysis of variance) and presented in Table 2 and Equations (2) and (4).

The ANOVA data for the predicted model of galactooligosaccharidesn yield (GOS) was presented in Table 2. The varioon of the GOS (g/L) data were fitted and represented by regression Equation (4). The F value (19.32) indicates that the predicted model was highly significant with a p value of < 0.0001. Furthermore, the high-value coefficient of determination value (R^2 = 0.91) and adjusted R^2 = 0.86 are also an indication of good fitness of the model to experimental data of GOS yield. The F value (19.32) indicated that the quadratic term of microwave power significantly affected the model of extraction of galactooligosaccharides yield. The negative value of linear terms describes that an increase in microwave power, time, and water to flour ratio resulted in a decrease in extraction of galactooligosaccharides in the extracted solution. The adverse effect of high microwave power was also reported by Carrero-Carralero et al. (2018) for the mung bean. The quadratic term of microwave power was also significant for the GOS yield.

$$Y_{GOS} = +5.34908 + 0.020A - 0.197B - 0.737C - 2.36 \times 10 - 5AB + 7.12 \times 10 - 6BC + 0.0201AC - 0.000024A2, \quad (4)$$

where, Y_{GOS} = GOS in ricebean oligosaccharides water extract, A = microwave power (W), B = time (minutes), and C = W to F ratio (mL/g),

Response surface graphs was illustrated to study the effects of parameters and their interactive effect in the microwave heating process on the GOS yield (Figure 1a). From Figure 1a, the GOS yield increased with an increase in microwave power up to

TABLE 2 | Analysis of variance (ANOVA) and model coefficients presenting the effect of microwave heating on responses.

Parameter	Galactooligosaccharides yield (g/L)	Total phenolic content (mg GAE/g)	Antioxidant activity (%)	pH
Intercept	+1.74	+150.94	+29.39	+5.44
A	−0.4311**	−13.25*	−13.09**	−0.2009**
B	−0.1305*	−15.49*	−0.9230*	+0.0100^{ns}
C	−0.2080*	−18.77*	−6.52*	−0.0050^{ns}
AB	−0.1416^{ns}	−7.01^{ns}	−7.18^{ns}	—
AC	+0.0043^{ns}	+17.06*	−0.5928^{ns}	—
BC	+0.1817*	+7.39^{ns}	+4.38*	—
A^2	−0.9565**	—	—	—
B^2	−0.0644^{ns}	—	—	—
C^2	+0.1439^{ns}	—	—	—
R^2	0.91	0.76	0.86	0.64
Lack of fit	0.097^{ns}	0.088^{ns}	0.061^{ns}	—
Adj R^2	0.86	0.69	0.83	0.59
p value	< 0.0001	< 0.0001	0.0017	0.0061
F value	19.32	10.75	22.20	13.68

Note: *A* = microwave power (W), *B* = time (minutes), *C* = W to F ratio (mL/g), ns = non-significant.
*$p < 0.05$.
**$p < 0.01$.

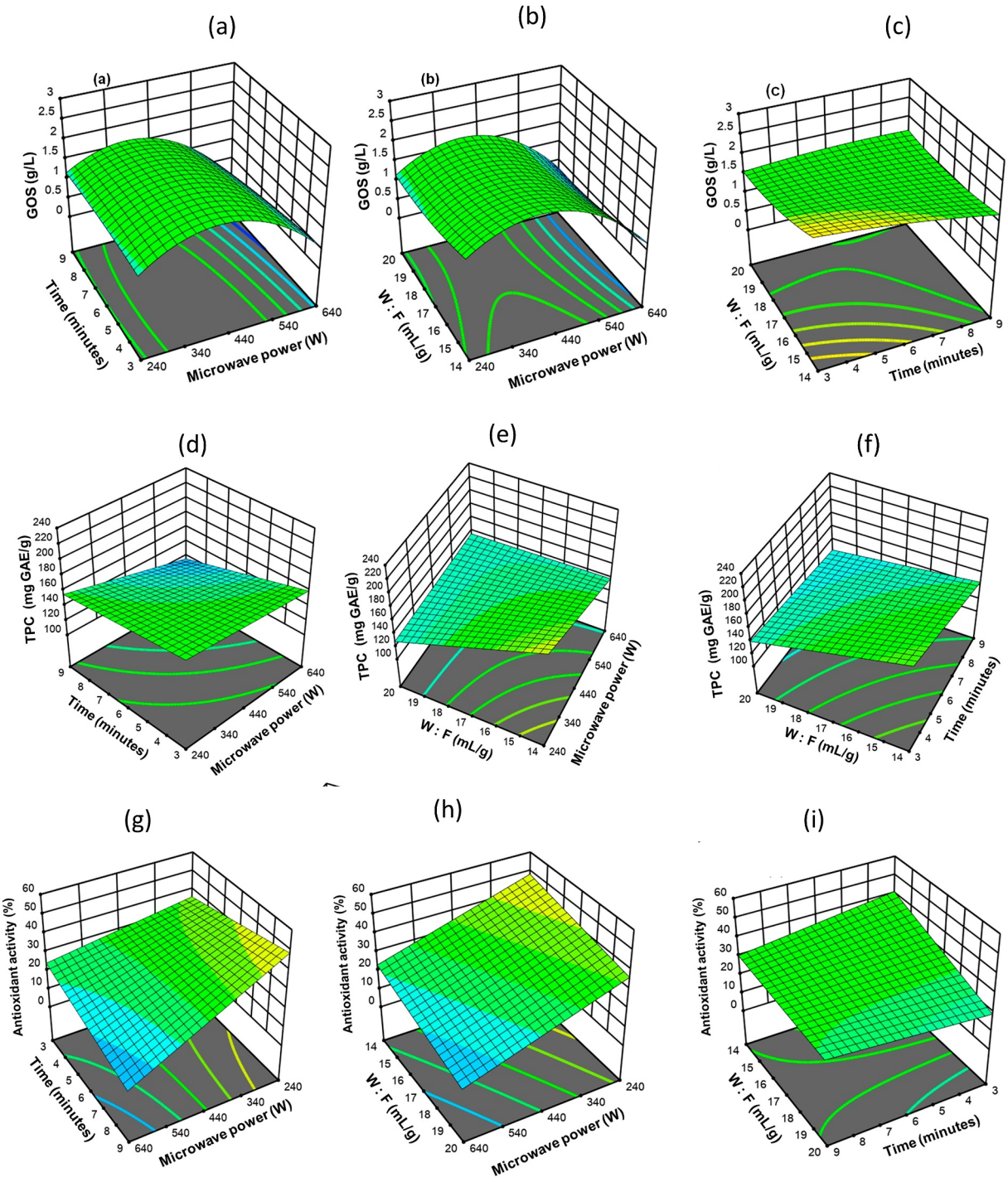


FIGURE 1 | Effects of independent variables power and time, microwave power and W to F ratio, and time and W to F ratio on the extraction of (a–c) galactooligosaccharides, (d–f) TPC and (g–i) antioxidant activity.

440 W and beyond this, it decreased. This might be due to the saturation of GOS, leading to no significant effect of microwave power on the ricebean samples.

Microwave power has a significant effect on the galactooligosaccharides (GOS) as it improves the extraction by providing the thrust for breaking the ricebean flour matrix. The prolonged microwave heating causes a slight increase in the concentration of galactooligosaccharides in the extracts, leading to the cessation of migration of GOS from ricebean flour to GOS extract water; this might be attributed to the complete fragments of carbohydrate within the ricebean. However, the adverse effect of using excessive microwave power (640 W) on the extraction of GOS was observed (Figure 1a). The obtained adverse effect might be attributed to the evaporation of water which stimulated the mass transfer barrier for elution of GOS to water. The interaction between microwave power and W to F ratio in Figure 1b showed that

with an increase in the water to flour ratio (for all microwave power), a decrease in the concentration of GOS was observed. This might be due to the dilution effect of the solvent. Nevertheless, the interaction between heating time and water to flour ratio indicated that prolonged heating at higher W to F ratio might not be useful as no increase in extraction of GOS was observed (Figure 1c).

3.2 | Effect of Independent Variables on TPC

The concentration of total phenolic content in ricebean oligosaccharides water extracts varied from 102.56 to 224.27 mg GAE/g. The model was adequate to fit experimental data with an R^2 value of 0.76 ($p < 0.0001$). The changes in the TPC (mg GAE/g) data were fitted and represented by regression Equation (5). The signal-to-noise ratio (greater than 4 is desirable) was 12.11, which was also an indication of adequate fitness of the model to experimental data. The predicted model can be used to steer the design space. The significant terms of the predicted model are the linear effect of microwave power, time, and W to F ratio, and the interaction term of microwave power and W to F ratio.

$$Y_{TPC} = +583.0 - 0.48A - 13.97B - 23.69C - 1.1 \times 10^{-2}AB + 0.029BC + 0.83AC, \quad (5)$$

where, Y_{TPC} = total phenolic content in ricebean oligosaccharides water extract, A = microwave power (W), B = time (minutes), C = W to F ratio (mL/g),

The combined effect of microwave power and time of heating on the extraction of total phenolic content was presented in Figure 1d. It was espied from Figure 1d, that increasing the power of microwave heating from 240 to 640 W, resulted in a slight reduction in the concentration of total phenolic content. The greatest reduction in the concentration of total phenolic content was observed at the highest power (640 W) and highest time (9 min). The reduction of TPC was might be due to the thermal degradation of phenolic compounds. A higher temperature led to the synthesis of new molecules or interactions between different compounds within ricebeans (De Lima Marsiglia et al. 2023). From Figure 1e,f, the highest concentration of total phenolic compound was observed at 240 W power and 1:14 W to F ratio. Thereafter, by increasing either power or W to F ratio, a reduction in total phenolic content of extracts was observed. The reduction might be due to the dilution effect of using too much solvent. The time has no significant effect on the TPC content this might be due to insufficient reaction within ricebean. Similar results were also reported by Ballard et al. (2010), Singh et al. (2011), and Tsubaki et al. (2010) for peanut skins, tea leaves, and potato peels, respectively.

3.3 | Effect of Independent Variables on Antioxidant Activity

Antioxidants are important food additives to reduce the oxidative degradation of many food products. The variability of antioxidants % in the extracts at different conditions of the microwave heating process was evaluated using a regression models. The varitions in antioxidant of experimental data were fitted and represented by Equation (6). The interaction of time and flour to water ratio has a significant effect on the antioxidant of the ricebean GOS extract. The analysis of variance (ANOVA) data indicated that the obtained model was significant (Table 2) at 1% and 5% level of significance. The linear terms of microwave power and time significantly influenced the antioxidant activity of the ricebean GOS extract. This might be due to disturbed cell wall and released more sugar and phenolic compounds.

$$Y_{AC} = +107.60 + 0.023A - 3.31B - 4.65C - 1.1 \times 10^{-2}AB + 9.88 \times 10^{-4}BC + 0.48AC, \quad (6)$$

where, Y_{AC} = antioxidant activity (%), A = microwave power (W), B = time (minutes), C = W to F ratio (mL/g),

From Figure 1g, it was espied that when the solution of ricebean flour and water was heated at low microwave power (240 W), a high amount of antioxidants leached out to the water. Thereafter, the adverse effect of using high microwave power was also observed in the case of antioxidants during the experiments. Addtionally, when water was added in higher amounts to flour, a very low antioxidant activity in extracts was detected [Figure 1h,i].

3.4 | Effect of Extraction Conditions on pH

The pH of the ricebean GOS extracts was varied from 5.21 to 5.95 at different combination of experiments. F value (13.68) indicated that the linear model was significant for GOS extract of ricebean (Equation 7). However, only the linear effect of microwave power was found to significantly affect the pH of GOS extracts.

$$Y_{pH} = +5.89 - 9.72 \times 10^{-4}A + 01.29 \times 10^{-4}B - 1.66C, \quad (7)$$

where, Y_{pH} = pH of ricebean GOS extract, A = microwave power (W), B = time (minutes), C = W to F ratio (mL/g),

The effect of microwave power on the pH of extracts is illustrated in Figure 2. A decrease in the pH of extracts was observed when the microwave power was increased from 240 to 640 W. This might be due to higher leaching of amino acids to water, and also the breakdown of ricebean starch could release acids at higher microwave power and result in a decrease in the pH of the extract (Li et al. 2018).

3.5 | Optimization and Validation

The numerical optimization of the microwave heating process was done based on obtained response values. The dependent responses were maximized or kept in range, whereas all the independent variables were kept in the range based on the desirability of the ricebean GOS extracts. The optimum conditions to maximize the GOS yield were 400 W microwave power, 3 min time, 14:1 W to F ratio in the ricebean flour at maximum desirability score of 0.77. For the validation of optimized conditions (400 W microwave power, 3 min time,

14:1 W to F ratio), the experiment was performed and the responses were measured. The predicted and actual experimental values are presented in Table 3. The percentage absolute residual error (ARE %) of less than 5% indicated that the obtained experimental values were in close agreement with the predicted values, which demonstrated the validation of the model.

4 | Conclusions

The customized full factorial design was used to optimize the extraction parameters of microwave heating. In conclusion, our results suggest that the microwave extraction technique has great potential to extract the GOS from ricebean. The GOS yield, total phenolic content, antioxidant activity, and pH during the microwave-assisted extraction process was ranged from 0.18 to 2.84 g/L, 102.56–224.67 mg GAE/g, 5.32%–55.73%, and 5.21 to 5.95, respectively. The predicted model was developed and the ANOVA test indicated the developed model was statistically significant ($p < 0.05$). The obtained optimum GOS extraction conditions were 400 W microwave power, 3 min time, 14:1 W to F ratio, and a maximum desirability score of 0.77. Based on the calculated absolute residual error, the experimental values were in close agreement with the software predicted values.

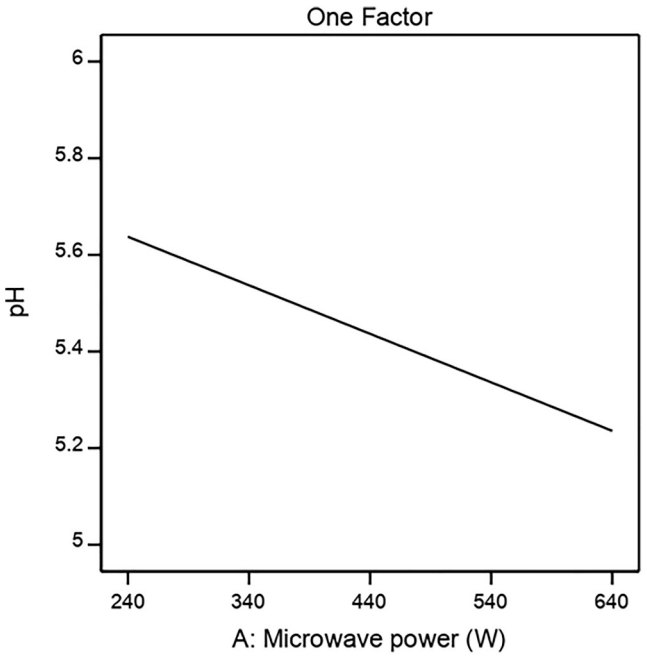


FIGURE 2 | Effect of microwave power on pH of ricebean GOS water extracts.

Author Contributions

Bharat Bhushan: writing – original draft, investigation, methodology. **Rakesh Kumar Raigar:** conceptualization, software, investigation, supervision, writing – review and editing.

Ethics Statement

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Ballard, T. S., P. Mallikarjunan, K. Zhou, and S. O'Keefe. 2010. "Microwave-Assisted Extraction of Phenolic Antioxidant Compounds From Peanut Skins." *Food Chemistry* 120, no. 4: 1185–1192. https://doi.org/10.1016/j.foodchem.2009.11.063.

Barreteau, H., C. Delattre, and P. Michaud. 2006. "Production of Oligosaccharides as Promising New Food Additive Generation." *Food Technology and Biotechnology* 44, no. 3: 323–333.

BeMiller, J. N. 2018. "Carbohydrate Chemistry for Food Scientists." In *Oligosaccharides*. Chapter 3, 49–74. https://doi.org/10.1016/C2016-0-01960-5.

Carrero-Carralero, C., D. Mansukhani, A. I. Ruiz-Matute, I. Martínez-Castro, L. Ramos, and M. L. Sanz. 2018. "Extraction and Characterization of Low Molecular Weight Bioactive Carbohydrates From Mung Bean (Vigna radiata)." *Food Chemistry* 266: 146–154. https://doi.org/10.1016/j.foodchem.2018.05.114.

De Lima Marsiglia, W. I. M., L. D. S. C. Oliveira, R. L. J. Almeida, et al. 2023. "Thermal Stability of Total Phenolic Compounds and Antioxidant Activities of Jaboticaba Peel: Effect of Solvents and Extraction Methods." *Journal of the Indian Chemical Society* 100, no. 5: 100995. https://doi.org/10.1016/j.jics.2023.100995.

de Menezes, C. R., Í. S. Silva, É. C. Pavarina, et al. 2009. "Production of Xylooligosaccharides From Enzymatic Hydrolysis of Xylan by the White-Rot Fungi Pleurotus." *International Biodeterioration & Biodegradation* 63, no. 6: 673–678. https://doi.org/10.1016/j.ibiod.2009.02.008.

de Moura, F. A., F. T. Macagnan, and L. P. da Silva. 2015. "Oligosaccharide Production by Hydrolysis of Polysaccharides: A Review." *International Journal of Food Science and Technology* 50, no. 2: 275–281. https://doi.org/10.1111/ijfs.12681.

TABLE 3 | Comparison of predicted value and experimental value of optimized conditions.

Response	Predicted value	Experimental value	ARE (%)
Galactooligosaccharides (g/L)	2.358	2.58 ± 0.14	4.92
Total phenolic content (mg GAE/g)	197.24	196.41 ± 0.29	0.42
Antioxidant activity (%)	42.26	40.84 ± 0.36	3.47
pH	5.472	5.46 ± 0.10	0.22

Eltayeb, A. R. S., A. O. Ali, A. A. Abou-Arab, and F. M. Abu-Salem. 2011. "Chemical Composition and Functional Properties of Flour and Protein Isolate Extracted From Bambara Groundnut (Vigna Subterranean)." *African Journal of Biotechnology* 5, no. 2: 82–90.

Fernando, W. M. U., J. E. Hill, G. A. Zello, R. T. Tyler, W. J. Dahl, and A. G. Van Kessel. 2010. "Diets Supplemented With Chickpea or Its Main Oligosaccharide Component Raffinose Modify Faecal Microbial Composition in Healthy Adults." *Beneficial Microbes* 1, no. 2: 197–208doi. https://doi.org/10.3920/BM2009.0027.

Gyawali, R., N. Nwamaioha, R. Fiagbor, T. Zimmerman, R. H. Newman, and S. A. Ibrahim. 2019. "The Role of Prebiotics in Disease Prevention and Health Promotion." In *Dietary Interventions in Gastrointestinal Diseases: Foods, Nutrients, and Dietary Supplements*, 151–167. Academic Press. https://doi.org/10.1016/B978-0-12-814468-8.00012-0.

Katoch, R. 2013. "Nutritional Potential of Rice Bean (Vigna Umbellata): An Underutilized Legume." *Journal of Food Science* 78, no. 1: C8–C16. https://doi.org/10.1111/j.1750-3841.2012.02989.x.

Katoch, R., S. K. Sanadya, K. Pathania, and H. K. Chaudhary. 2023. "Nutritional and Nutraceutical Potential of Rice Bean (Vigna umbellata) —A Legume With Hidden Potential." *Frontiers in Nutrition* 10: 1126544. https://doi.org/10.3389/fnut.2023.1126544.

Kunová, G., V. Rada, I. Lisová, Š. Rocková, and E. Vlková. 2011. "In Vitro Fermentability of Prebiotic Oligosaccharides by Lactobacilli." Supplement, *Czech Journal of Food Sciences* 29, no. Special Issue: S49–S54. https://doi.org/10.17221/306/2011-CJFS.

Kupina, S., C. Fields, M. C. Roman, and S. L. Brunelle. 2019. "Determination of Total Phenolic Content Using the Folin-C Assay: Single-Laboratory Validation, First Action 2017.13." *Journal of AOAC International* 101, no. 5: 1466–1472. https://doi.org/10.5740/jaoacint.2017.13.

Li, H., C. J. Wu, and S. J. Yu. 2018. "Impact of Microwave-Assisted Heating on the Ph Value, Color, and Flavor Compounds in Glucose-Ammonium Model System." *Food and Bioprocess Technology* 11, no. 6: 1248–1258. https://doi.org/10.1007/s11947-018-2093-6.

Maurya, A. K., and P. P. Said. 2014. "Extrusion Processing on Physical and Chemical Properties of Protein Rich Products-An Overview." *Journal of Bioresource Engineering and Technology* 2, no. 4: 61–67.

Mena-García, A., A. I. Ruiz-Matute, A. C. Soria, and M. L. Sanz. 2019. "Green Techniques for Extraction of Bioactive Carbohydrates." *TrAC Trends in Analytical Chemistry* 119: 115612. https://doi.org/10.1016/j.trac.2019.07.023.

Raigar, R. K., R. Upadhyay, and H. N. Mishra. 2017. "Optimization of Microwave Roasting of Peanuts and Evaluation of Its Physicochemical and Sensory Attributes." *Journal of Food Science and Technology* 54, no. 7: 2145–2155. https://doi.org/10.1007/s13197-017-2654-0.

Rostami, H., and S. M. T. Gharibzahedi. 2016. "Microwave-Assisted Extraction of Jujube Polysaccharide: Optimization, Purification and Functional Characterization." *Carbohydrate Polymers* 143: 100–107. https://doi.org/10.1016/j.carbpol.2016.01.075.

Ruiz-Aceituno, L., M. J. García-Sarrió, B. Alonso-Rodriguez, L. Ramos, and M. L. Sanz. 2016. "Extraction of Bioactive Carbohydrates From Artichoke (Cynara scolymus L.) External Bracts Using Microwave Assisted Extraction and Pressurized Liquid Extraction." *Food Chemistry* 196: 1156–1162. https://doi.org/10.1016/j.foodchem.2015.10.046.

Setyaningsih, W., A. W. Putro, R. N. Fathimah, et al. 2022. "A Microwave-Based Extraction Method for the Determination of Sugar and Polyols: Application to the Characterization of Regular and Peaberry Coffees." *Arabian Journal of Chemistry* 15, no. 3: 103660. https://doi.org/10.1016/j.arabjc.2021.103660.

Singh, A., K. Sabally, S. Kubow, et al. 2011. "Microwave-Assisted Extraction of Phenolic Antioxidants From Potato Peels." *Molecules* 16, no. 3: 2218–2232. https://doi.org/10.3390/molecules16032218.

Su, D. L., P. J. Li, S. Y. Quek, et al. 2019. "Efficient Extraction and Characterization of Pectin From Orange Peel by a Combined Surfactant and Microwave Assisted Process." *Food Chemistry* 286: 1–7. https://doi.org/10.1016/j.foodchem.2019.01.200.

Thirugnanasambandham, K., V. Sivakumar, and J. P. Maran. 2015. "Microwave-Assisted Extraction of Polysaccharides From Mulberry Leaves." *International Journal of Biological Macromolecules* 72: 1–5. https://doi.org/10.1016/j.ijbiomac.2014.07.031.

Tsubaki, S., M. Sakamoto, and J. I. Azuma. 2010. "Microwave-Assisted Extraction of Phenolic Compounds From Tea Residues Under Autohydrolytic Conditions." *Food Chemistry* 123, no. 4: 1255–1258. https://doi.org/10.1016/j.foodchem.2010.05.088.

Van den Ende, W. 2013. "Multifunctional Fructans and Raffinose Family Oligosaccharides." *Frontiers in Plant Science* 4: 247. https://doi.org/10.3389/fpls.2013.00247.

Vinjamoori, D. V., J. R. Hayes, and T. K. Das. 2004. "Challenges and Opportunities in the Analysis of Raffinose." *Journal of Animal Science* 82, no. 1: 319–328.

Zhang, Y., Y. Li, P. Wang, Q. Liang, Y. Zhang, and F. Ren. 2019. "The Factors Influencing Rennet-Induced Coagulation Properties of Yak Milk: The Importance of Micellar Calcium During Gelation." *Lwt Food Science and Technology* 111: 500–505. https://doi.org/10.1016/j.lwt.2019.05.015.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.

Table S1: Actual and coded (levels) values of independent variables and experimental values of responses in full factorial design.