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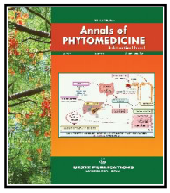

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Physicochemical and functional properties of dietary fibres extracted from the pseudostem of *Musa balbisiana* Colla

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Abstract

Taking banana variety *Musa balbisiana* Colla as raw material, dietary fibre from its pseudostem was extracted by using alkaline extraction method. Response surface methodology (RSM) was used to optimise the extraction process and investigate the impact of temperature, agitation speed, and extraction time on the yield of dietary fibre. According to the optimisation result, the following values for the extraction process parameters were found to be ideal: agitation speed of 300 rpm, temperature of 58.92ºC, and duration of 41.89 min. These conditions yielded 77.05% of dietary fibre. The extracted dietary fibre showed high dietary fibre content, insoluble dietary fibre in particular. It showed improved physicochemical and functional properties. These properties indicate the potential of the extracted dietary fibre as a nutraceutical with hypoglycemic and hypocholesterolemic properties.

1. Introduction

Throughout the world's tropical and sub-tropical regions, more than thirty countries cultivate the banana (Musa), a tropical herbaceous plant with significant economic value. With rice, wheat, and maize as the top three most consumed staples, it is one of them. The states that produce the most bananas in India are Maharashtra, Kerala, Tamil Nadu, Gujarat, Bihar, West Bengal, Assam, Andhra Pradesh, and Karnataka. Bananas are the second most produced fruit in the country, behind mangoes (Shiva *et al*., 2018). With an annual production of 30.18 million tonnes, India is world's top banana producer, according to the National Horticulture Board. Thirteen per cent of all the land used for fruit cultivation and thirty-three per cent of all the fruit produced in the nation is used for banana agriculture. Assam, a state in north-eastern India, is one of the leading producers of bananas, contributing over 2.4 % of the nation's total output (Hazarika *et al.,* 2020). In Assam, banana farming is extremely important in both economic and socio-cultural aspect. Banana cultivation generates substantial employment opportunities, especially in rural areas, involving small and marginal farmers. Apart from its horticultural importance, the banana plant is also a part of several Assamese traditional rites (Medhi, 2021). Assamese cuisine heavily incorporates the fruit and plant parts of *M. balbisiana*, an indigenous type of banana.

Banana pseudostems are biomasses generated after harvesting of the banana fruit and are storehouse of nutrients and health benefits. Ayurveda has elucidated the benefit of banana pseudostem as an ethnomedicine for gastrointestinal problems; namely, bloating, gastritis, constipation and colitis (He *et al.,* 2022). It is reported to be rich in nutrients such as minerals like sodium, potassium, chromium, magnesium, zinc, copper, iron and phosphorus, dietary fibre and antioxidant. Banana pseudostems are abundant sources of dietary fibre (50-70%) which helps in regulating the gut function and gut microbial biomass (Suhaimi *et al.,* 2020). Other benefits include weight management, improvement of satiety, regulation of glucose and insulin response and cholesterol management (Raju *et al.,* 2019). Studies suggest the significance of dietary fibres in the management of diabetes and prevention of colon cancer. Dietary fibres have low calorie and exhibit the presence of several vitamins, minerals and antioxidants (Soujanya *et al.,* 2021). The presence of dietary fibre in the banana pseudostem has been reported to have immense role in biomedical as well as food processing industries (Chakraborty *et al.,* 2020). Hence, the extraction of dietary fibre from banana pseudostem would potentially be immensely useful in both nutraceutical as well as food processing industry. Dietary fibres have been widely accepted as an important functional ingredient in the prevention and management of health disorders.

With the increase in urbanisation of food culture, there has been a tremendous spike in the occurrence of diet-related disorders such as diabetes mellitus and cardiovascular disorders. Another significant factor contributing to the ongoing global increase in metabolic diseases like diabetes, which is predicted to affect 366 million people over 65 years in 2030, is the tendency towards sedentary lifestyles (Swetha and Velraj, 2023). Therefore, implementation of preventive strategies is needed to overcome the health-associated challenges. One of the most effective and sustainable majors could be utilisation of the functional attributes of plant products (Sharma and Sarwat, 2022). Plant sources have been known to demonstrate promising preventive

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action against metabolic syndromes, paving the way for the discovery of newer plant-based sources with therapeutic compounds. Therefore, it is imperative to delve into the functional attributes to identify novel hypoglycemic and hypocholesterolemic treatments that offer a more favourable safety profile (Eshan *et al.,* 2023). Furthermore, utilising plant biomasses such banana pseudostem could help control waste generation and associated environmental risks by composting the organic waste as nutraceutical (Gaikwad *et al.,* 2021).

Studies conducted on different banana varieties such as *M. acuminate, M. balbisiana* cv. *awak* and *M. sapientum* species have confirmed that the dietary fibre present in their pseudostems have good nutritional as well as functional properties. Banana pseudostem can be utilised in biomedical industry as a nutraceutical and dietary fibre supplement (Maskey *et al.,* 2020). Scientific literature about the dietary fibre profile of the pseudostem of the banana cultivar *M. balbisiana* is still lacking, nevertheless. Therefore, the objective of this work is to identify the components, physicochemical characteristics, and functional attributes of the dietary fibre extracted from the pseudostem of *M. balbisiana* using an optimised model.

2. Materials and Methods

2.1 Collection and preparation of sample

The pseudostems of *Musa balbisiana* were gathered from the Assam Agricultural University campus in Jorhat, Assam. The pseudostems were washed and cut transversally into thin slices of 4 millimetres using a slicer. To keep the slices from browning, they were immersed in a 4% (w/v) citric acid solution for 10 min. For 20 h, the sliced pseudostems were dried at 56°C in a laboratory oven. The moisture content of the dried pseudostem slices was estimated using moisture analyser operated at 105°C for 10 min. The dried pseudostems were powdered in a domestic grinder at the rate of 100 g/2 min and stored for further use. The ground samples were estimated for fat content by Soxhlet extraction method.

2.2 Optimisation of parameters for extraction of dietary fibre

Response surface methodology (RSM) was utilised to optimise the extraction process of dietary fibre. With the help of Design Expert Version 7.0.0, a set of 20 tests (Table 1) was created using the central composite design (CCD) technique of RSM, with the ranges of extraction time, temperature, and agitation speed being 10-50 min, 41.08-65°C, and 240.54-400 rpm, respectively. The response was acquired for every run at the conclusion of the studies.

Table 1: Limits of the variables used for extraction of dietary fibre

Parameters	Lower limit	Upper limit
Temperature (°C)	41.08	58.92
Time (min)	18.11	41.89
Agitation speed (rpm)	240.54	359.46

After the results of the 20 tests were examined, a model equation was created that correlated the extraction parameters: temperature, duration, and agitation speed to the total amount of dietary fibre. The Design Expert Version 7.0.0 analysis tool made changes to these data. The derived model equation was optimised to produce the maximum total dietary fibre yield using the program's optimisation tool. Table 1 displays the limits of the independent variables that were acquired by modification in the optimisation model.

2.3 Extraction of dietary fibre

The alkaline extraction method described by Ma and Mu, 2016 and Zhang *et al.* (2017) was used to extract dietary fibre. After mixing the powdered sample with 0.5 M NaOH (pH 13.69), it was stirred for 30 min at 50°C using a magnetic stirrer. After that, 0.5 M HCl (pH 0.3) was used to neutralise it. After 1 h of standing time, 85% ethanol (2:1 v/v) was added to collect the precipitate. After that, the solution was centrifuged. Three washes with distilled water were performed on the centrifuged material. After that, the pellet was dried for 12 h at 40°C. For additional analysis, the extracted material was kept in refrigeration at a temperature of 2°C.

2.4 Determination of dietary fibre contents

2.4.1 Total dietary fibre, soluble dietary fibre, insoluble dietary fibre

Total dietary fibre, soluble dietary fibre, insoluble dietary fibre was estimated using enzymatic gravimetric method. The extracted sample obtained was digested in a sequential enzymatic process by heat stable α-amylase, protease and amyloglycosidase for the removal of starch and protein. The sample was added with the enzyme digestase, filtered, and the residue was washed with warm water, dried, and weighed in order to calculate the amount of insoluble dietary fibre (IDF). The filtrate was mixed with alcohol to precipitate washes for soluble dietary fibre (SDF), which was subsequently filtered, dried, and weighed. The total of IDF and SDF was used to calculate total dietary fibre (TDF) (AOAC,1997).

2.4.2 Cellulose, hemicellulose and lignin

Neutral and acid detergent fibres were measured in order to determine the insoluble fractions. Estimates of lignin, neutral detergent fibre (NDF), and acid detergent fibre (ADF) were made using a slightly modified version of the Van Soest (1967) and McQueen and Nicholson (1979) methods. The following formulas were used to estimate the contents of hemicellulose and cellulose: hemicellulose = NDF-ADF and cellulose = ADF-lignin, respectively.

2.4.3 Pectin

The total pectin content was estimated according to the method described by Ranganna (1979).

2.5 Determination of physicochemical properties

The physicochemical properties of the extract was compared with cellulose (sulfoxyethyl cellulose fast flow, fibres)

2.5.1 Bulk density

3 g each of the extracted sample and cellulose was placed in 50 ml graduated cylinders. The cylinder was tapped on a rubber sheet to pack the contents until a consistent volume was reached. Bulk density was given as g/ml for the sample.

2.5.2 Water holding capacity (WHC)

250 mg of the extracted material and 250 mg of cellulose were combined with 25 ml of distilled water. After stirring, this mixture was allowed to sit for 1 h at room temperature (25°C). After centrifuging it for 20 min at 3000 g, the supernatant was decanted. To make sure that the water was properly removed from the residue, the centrifuge tubes were allowed to drain completely. Weighing the resultant residue was done. WHC was expressed as g water per g dry sample (Rodrý Guez *et al.,* 2006).

2.5.3 Oil holding capacity (OHC)

250 mg of the extracted material and 250 mg of cellulose were combined with 25 ml of olive oil. After agitating the mixture, it was incubated for one hour at room temperature (25°C). After centrifuging it for 20 min at 3000 g, the supernatant was decanted. The centrifuge tubes were allowed to completely empty in order to guarantee that the oil was properly removed, leaving behind residue. Weighing the residue was done. OHC was expressed as g water per g dry sample (Rodrý Guez *et al.,* 2006).

2.5.4 Swelling capacity (SC) and solubility

Weighing 0.5 g of cellulose and extracted dietary fibre, 50 ml dry centrifuge tubes were previously tarred. The centrifuge tubes were pipetted with 20 ml of distilled water. After 30 min of room temperature stirring with a magnetic stirrer, the suspensions were centrifuged for 30 min at 3500 g. SC was measured in g of swollen granules per g of dry material by analysing the residue left over after centrifugation.

At 110°C, the supernatant aliquots were dried to a consistent weight. The residue collected served as a measure of the sample's solubility in water and was given as g of dry weight per g of dry sample (Adebowale *et al.,* 2002).

2.5.5 Cation exchange capacity (CEC)

For 48 h, 1 g of the extracted material and 1 g of cellulose combined with 2 M HCl were left on stand. From the combination, 0.5 g of the wet sample was removed, and the volume was increased to 100 ml using 5% NaCl in buffer (pH 6.9) before filtering. After that, the sample was titrated and shook for 60 min at 37°C. Weighing the residue was done. CEC was expressed as meq/g of dry weight per g of dry sample (Gorecka *et al.,* 2000).

2.6 Determination of functional properties

2.6.1 Glucose adsorption capacity (GAC)

GAC was determined using the Peerajit *et al.* (2012) method. A 100 ml glucose solution containing 18 mg/l was combined with 1 g of the extracted material and cellulose. A magnetic stirrer was used to stir the mixture, and it was then incubated for 6 h at 300 rpm in a water bath at 37°C. After that, it was centrifuged for 20 min at 4000 g. The supernatant was weighed. Anthrone method was used to calculate the glucose concentration. The following formula was used to determine the amount of GAC (mg/g):

$$\text{GAC} = \frac{\text{Initial glucose concentration} - \text{Final glucose concentration}}{\text{Weight of the sample} \times \text{Volume of the supernatant}}$$

2.6.2 Cholesterol adsorption capacity (CAC)

CAC was calculated using the method outlined by Xu *et al.* (2015). Distilled water was used to dilute fresh egg yolk (9 times volume). 50 ml of an egg yolk mixture was combined with 2 g of the extracted sample and cellulose at pH 2.0 and pH 7.0, respectively, to replicate the pH conditions in the stomach and small intestine. After being shaken for 2 h at 100 rpm in a water-bath incubator at 37°C, the mixture and the blank control were centrifuged for 15 min at 4000 g. The amount of cholesterol in the supernatant was measured with ammonium ferric sulphate at 550 nm. The following formula was used to determine CAC:

$$\text{CAC} = \frac{\text{Initial cholesterol concentration} - \text{Final cholesterol concentration}}{\text{Weight of the sample} \times \text{Volume of the supernatant}}$$

2.7 Statistical analysis

The paired t-test was used to statistically assess the data. The confidence interval was 95%, and the mean values from three replicates with standard deviations (SD) were shown.

3. Results

3.1 Optimisation of parameters for extraction of dietary fibre

The levels of variables in the 20 experimental runs along with the responses are represented in Table 2. It is observed that there is variation in the values of response with varying extraction parameters. The total dietary fibre yield was different in all the 20 experimental runs.

Table 2: Designed experimental runs and observed responses

Experiment No.	Independent variables			Response
	Time (min)	Temperature (^{0}C)	Speed (rpm)	Total dietary fibre (%)
1	30	50	300	75.92
2	30	50	300	76.04
3	18.18	41.08	359.46	73.28
4	10	50	300	73.62
5	41.89	58.92	359.46	81.97
6	18.12	58.92	359.46	77.88
7	50	50	300	80.15
8	41.89	58.92	240.54	81.31
9	18.12	41.08	240.54	71.28
10	30	50	300	75.89
11	30	65	300	81.48
12	30	50	200	74.87

13	41.89	41.08	359.46	75.45
14	30	35	300	71.53
15	30	50	300	76.02
16	41.89	41.08	240.54	74.47
17	18.12	58.92	240.54	76.24
18	30	50	400	77.21
19	30	50	300	76.18
20	30	50	300	76.26

The coded regression equation obtained between the variables and response is as follows: $R1=76.05+1.88a+2.90b+0.67c+0.475ab-0.25ac-0.085bc+0.29a^2+0.166b^2-0.007c^2$ where 'a' is the extraction time, 'b' is extraction temperature and 'c' is the agitation speed.

According to Table 3, analysis of variance (ANOVA) revealed that the regression sum of squares was statistically significant at the 95% confidence level. Coefficient of determination was high ($R^2=0.9988$), indicating a high proportion of variability explained by data. As a result, the predicted model accurately represents the observed data. The adequacy of the model is further justified by the fact that the values of R^2 (0.9988), adjusted R^2 (0.9978) and predicted R^2 (0.9953) are very close to each other. As these values are greater than 0.9, a significant correlation among the independent variables with the response is implied. As these values are greater than 0.9, a significant correlation among the independent variables with the response is implied. The fit statistics did not result in a significant F-value for the response, demonstrating that the model has the capacity to efficiently predict the response. As the coefficient of variation is very less than 10% (CV = 0.18%) for the response, better precision and reliability of the experimental runs is indicated. All the three variables, extraction time, temperature and agitation speed have significant effect on the response, *i.e.*, total dietary fibre yield. With increasing extraction time and temperature, the rate of extraction was observed to high as there was increased total dietary fibre yield indicating positive interaction between the two parameters ($p<0.05$). With respect to agitation speed, it was observed that the total dietary fibre yield diminished when the agitation speed was increased initially but reached a dynamic equilibrium at a constant agitation speed of 300 rpm. This indicated that the interaction of agitation speed is significant ($p<0.05$) but negative.

Table 3: ANOVA of the model and estimated coefficients for response

Source	Sum of squares	df	Mean	F-value	p-value	
Model	172.8322	9	19.20358	1002.501	1.42E-13	**Significant**
a-Extraction time	47.62132	1	47.62132	2486.016	2.54E-13	
b-Extraction temperature	115.1383	1	115.1383	6010.662	3.11E-15	
c-Agitation speed	6.21838	1	6.21838	324.6234	5.94E-09	
Ab	1.805	1	1.805	94.22795	2.09E-06	
Ac	0.5	1	0.5	26.10193	0.000458	
Bc	0.0578	1	0.0578	3.017383	0.11302	
a^2	1.21991	1	1.21991	63.684	1.2E-05	
ab^2	0.353397	1	0.353397	18.44868	0.001573	
ca^2	0.000878	1	0.000878	0.045849	0.834754	
Residual	0.191557	10	0.019156			
Lack of fit	0.087073	5	0.017415	0.833371	0.576829	**Non-significant**
Pure error	0.104483	5	0.020897	1002.501	1.42E-13	
Corrected total	173.0238	19				
Fit statistics						
Standard dev.	0.1384					
R^2	0.9988	**Adjusted R^2**	0.9978	**Predicted R^2**	0.9953	
Mean	76.352	**C.V %**	0.1812	**Adequacy precision**	111.288	

($p < 0.05$, the difference is significant).

The positive interaction of extraction time and temperature is depicted in the 3-D response surface map and contour plot in Figure 1 and Figure 2, respectively, which shows that there is an obvious increasing trend in the value of total dietary fibre yield, while extraction time and temperature increase. As the shape of the 3-D response surface map is closer to the ellipse, it indicates significant interaction between the extraction parameters, time and temperature on the total dietary fibre yield.

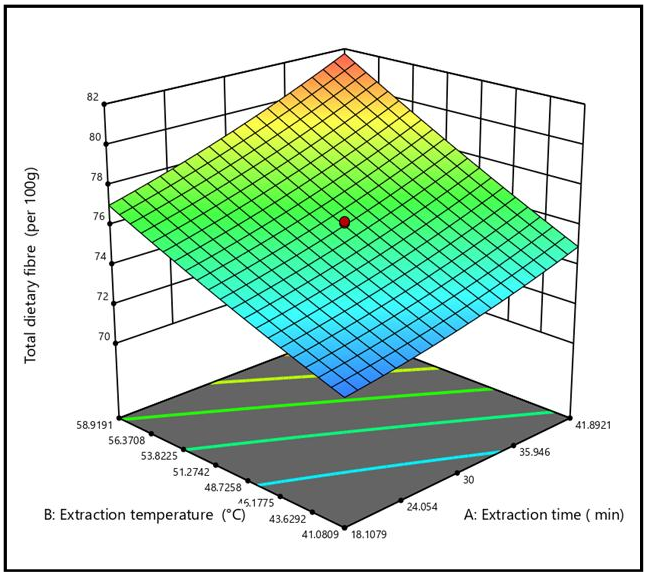

Figure 1: Response surface for the effects of extraction time and temperature on extraction efficiency of total dietary fibre.

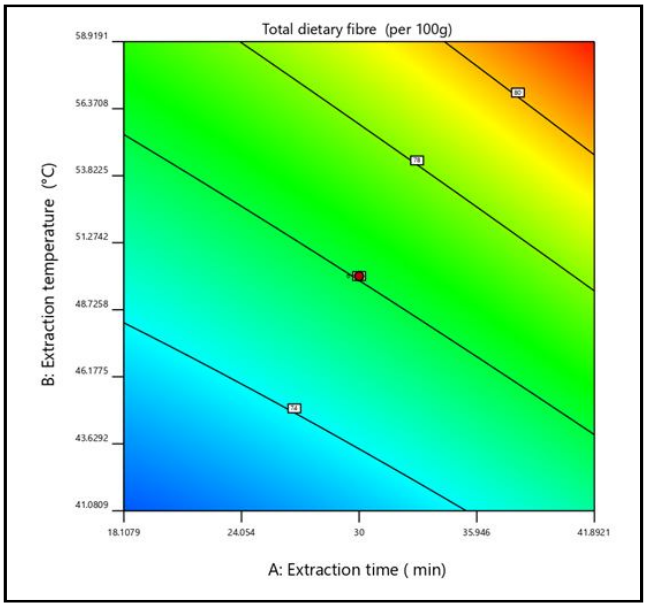

Figure 2: 3-D contour plot for the effects of extraction time and temperature on extraction efficiency of total dietary fibre.

After numerical optimisation of the fitted model, the optimal values of the variables that were modified and found were extraction time of 41. 89 min, extraction temperature of 58.92°C and agitation speed of 300 rpm. The predicted value of total dietary fibre was 76.36%. The validation of optimized conditions was done by conducting the extraction procedure using the obtained optimum range of parameters (time, temperature and agitation speed) and good agreement was found between actual and predicted values. The obtained total dietary fibre was 77.05%. The relative error between the actual total dietary fibre value and the theoretical prediction value is small. Therefore, this mathematical model has proven to be feasible for optimizing the extraction of banana pseudostem dietary fibre.

3.2 Dietary fibre (DF) constituents in the extracted dietary fibre

TDF in the extracted dietary fibre was 77.05 ± 1.10%. The dominant portion of the dietary fibre was insoluble dietary fibre of 73.88 ± 0.19%, while soluble dietary fibre was 3.16 ± 0.12%. The acid detergent fibre was 56.44 ± 1.17% and neutral detergent fibre was 71.26 ± 0.68%. Within the insoluble dietary ûbre fraction, cellulose content was 49.55 ± 0.47%, which was observed to be the most abundant, followed by hemicellulose of 14.82 ± 0.50% and lignin of 6.89 ± 0.07%. Within the soluble dietary fibre fraction, a low pectin content of 2.12 ± 0.02% was observed (Table 4).

Table 4: Dietary fibre contents in extracted DF from *M. balbisiana* pseudostem

Parameters (%)	Composition per 100 g
Insoluble dietary fibre	73.88 ± 0.19
Soluble dietary fibre	3.16 ± 0.12
Total dietary fibre	77.05 ± 0.06
Acid detergent fibre	56.44 ± 1.17
Neutral detergent fibre	71.26 ± 0.68
Hemicellulose	14.82 ± 0.50
Cellulose	49.55 ± 0.47
Lignin	6.89 ± 0.07
Pectin	2.12 ± 0.02

n = 3 ± S.D

3.3 Physicochemical properties of the extracted dietary fibre

When comparing the extracted dietary fibre from *M. balbisiana* pseudostem to cellulose, the physicochemical characteristics revealed a considerably lower bulk density and higher water holding capacity (WHC), oil holding capacity (OHC), swelling capacity (SC), solubility and cation exchange capacity (CEC) (Table 5). The extracted dietary fibre's bulk density was found to be 0.46 g/ml, significantly (p<0.05) "lower than that of cellulose (0.68 g/ml). The extracted dietary fibre has a significantly (p<0.05) higher water holding capacity (23.57 g/g) than cellulose (5.92 g/g). The extracted dietary fibre has an oil-holding capacity of 9.32 g/g, significantly (p<0.05) higher than that of cellulose (3.56 g/g). The dietary fibre that was extracted had a swelling capacity of 15.78 ± 0.41 ml/g, which was significantly (p<0.05) higher than the cellulose's swelling capacity of 4.23 ± 0.04 ml/g. The solubility value of 13.24 ± 1.13 found in the extracted dietary fibre fell within a comparable range to that of 13.00 ± 1.09 found in cellulose. The extracted dietary fibre had a CEC of 4.02 ± 0.27 mM/g, which is significantly (p<0.05) higher than the cellulose's value of 2.27 ± 0.15 mM/g.

Table 5: Physicochemical properties of extracted DF from *M. balbisiana* pseudostem

Physico chemical properties	Extracted dietary fibre from *M. balbisiana* pseudostem	Cellulose
Bulk density (g/ml)	0.46 ± 0.03[b]	0.68 ± 0.05[a]
WHC (g/g)	23.57 ± 1.02[b]	5.92 ± 0.86[a]
OHC (g/g)	9.32 ± 0.15[b]	3.56 ± 0.47[a]
SC (ml/g)	15.78 ± 0.41[b]	4.23 ± 0.04[a]
Solubility	13.24 ± 1.13[a]	13.00 ± 1.09[a]
CEC (mM/g)	4.02 ± 0.27[b]	2.27 ± 0.15[a]

n = 3 ± S.D

3.4 Functional properties of the extracted dietary fibre

The dietary fibre extracted from *M. balbisiana* pseudostem demonstrates significantly (p<0.05) higher functional properties in terms of glucose adsorption capacity (GAC) and cholesterol adsorption capacity (CAC) when compared to cellulose, as demonstrated by Figure 3 and Figure 4, respectively. The extracted dietary fibre had a GAC of 82.75 mg/g for glucose, compared to 64.21 mg/g for cellulose. In comparison to cellulose, which had a CAC of 12.65 mg/g and 11.29 mg/g at pH 7.0 and pH 2.0, respectively, the extracted dietary fibre had a capacity of 15.06 mg/g and 13.24 mg/g at pH 7.0 and pH 2.0, respectively.

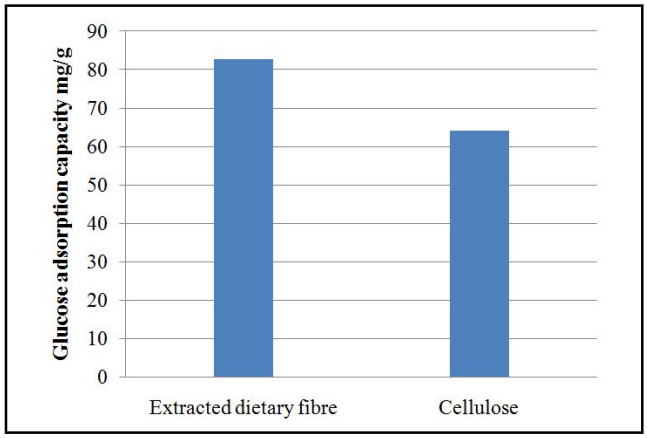

Figure 3: Glucose adsorption capacity (mg/g) of extracted DF from *M. bulbasiana* pseudostem.

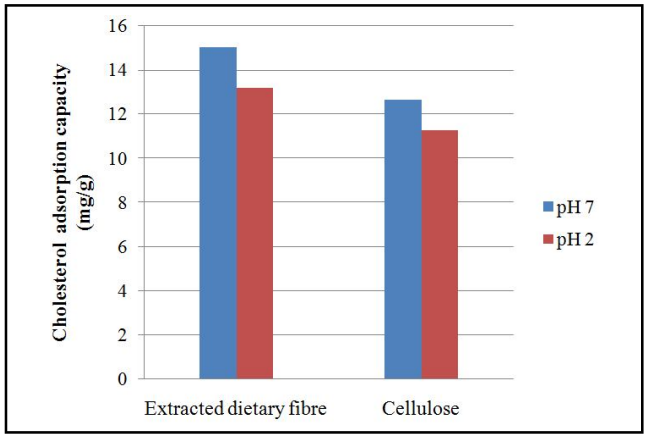

Figure 4: Cholesterol adsorption capacity (mg/g) of extracted DF from *M. bulbasiana* pseudostem.

4. Discussion

The statistical model obtained in the present study for extraction of dietary fibre was feasible in obtaining a set of optimum parameters: temperature, time and agitation speed with significance influence of all the parameters on total dietary fibre. The influence of agitation was observed to be negative after a certain point. Studies have reported that the process of extraction of dietary fibre is strongly influenced by the temperature and time used in the extraction process. By promoting the diffusion of hydrophilic biomolecules to liquid extraction, temperature enhances the hydrodynamic process of extraction and boosts the effectiveness of dietary fibre extraction. The chemical method of dietary fibre extraction requires longer time for higher dietary fibre extraction. In terms of agitation speed, it homogenises the extraction medium and quickens the rate at which molecules diffuse. However, exceeding the agitation speed beyond a certain point has adverse effect of the total dietary fibre yield and result in inefficient extraction (Bouaziz *et al.* (2014); Li *et al.,* 2019; Lei *et al.,* 2022). Bouaziz *et al*., 2014 reported a similar study on the optimisation of insoluble and soluble fibre extraction from *A. Americana* using RSM. The study reported that extraction time and temperature to have significant impact on the extraction efficiency, while the effect of agitation speed showed to have negative correlation. Similarly Li *et al*. (2019) conducted a study on optimisation of extraction of dietary fibre from potato peel by chemical method which reported extraction temperature to have the highest influence on the extraction efficiency, followed by time and agitation speed.

The extracted dietary fibre from *M. balbisiana* pseudostem yielded a high dietary fibre content of 77.05%. Several research findings have reported abundant presence (50-60%) of dietary fibre in banana pseudostem, particularly insoluble dietary fibre which includes cellulose, hemicellulose and lignin (Yangilar *et al.,* 2013). The pseudostem is mostly constituted with cellulosic material which results in higher levels of cellulose as well as hemicellulose, while it is comparatively low in lignin (Bhaskar *et al.,* 2011). Manilal and Sony (2011) has also reported cellulose to be the dominant constituent in banana pseudostem accounting to approximately 50%. This is in line with the study that was published by Aziz *et al*. (2011), whereby the native banana pseudostem exhibited 42.09% of cellulose, followed by 18.56% of hemicellulose, and the least reported was lignin accounting to 5.13%. Maskey *et al*. (2020) reported a study on different consumable parts of the banana plant which showed low pectin content of 2% in the pseudostem, while its content of cellulose was found to be high accounting to 26%.

Based on research done on the nutritional composition of the dietary fibre from the pseudostem of *M. bulbasiana* and other edible parts

of the banana plant, it is observed that the dietary fibre content is higher than those of culinary banana ûower (inner bract: 66% and outer bract:61%), banana fruit (unripe:14 % and ripe:1.1.-2.3%), banana peel (6.14-52.7%) and banana leaves (68%) (Philips *et al.,* 2021; Kumari *et al.,* 2023; Buljeta *et al*.,2023). Additionally, compared to rice bran and oat bran (27.04% and 26.40%, respectively), peach dietary fibre (30.7%), orange dietary fibre (35.4-36.9%), sesame coat dietary fibre (31.64%), soy pod dietary fibre (66%), and pineapple waste dietary fibre (64.43%), the extracted dietary fibre from *M. balbisiana* pseudostem has a much higher dietary fibre content (Luo *et al.,* 2017; Hadidi *et al.,* 2020; Dhar and Deka, 2022). The cellulose and hemicellulose obtained in the present study align with those reported by Aziz *et al*. (2011), who also noted that the pseudostem of bananas had less hemicellulose than cellulose (14.98% hemicellulose and 31.27% cellulose). The current investigation yielded greater lignin content than wheat and soy meal, which have lignin contents of only 0.88% and 0.58%, respectively. It is, nevertheless, less than plantain (14.3-16.8%) and banana pulp (6.0-12.1%) (He *et al*., 2022).

The extracted dietary fibre exhibited low bulk density. Larger particle size and spatial particle distribution of dietary fibre is associated with lower bulk density because of the increase in inter particle void (Ding *et al.,* 2020). Low bulk density is an important functional ability of dietary fibre as it facilitates its primary physiological functions such as fermentation, bacterial degradation and hydration in the gastrointestinal tract (Dong *et al.,* 2020). The current study's findings are consistent with the research published by Begum and Deka (2019), who found that the dietary fibre extracted from the inner and outer bracts of culinary bananas had bulk densities of 0.45 and 0.51 g/ml, respectively. The extracted dietary fibre showed improved water-holding capacity (WHC). Dietary fibres adsorb on the surfaces of macromolecules to keep water inside the interstices. Dietary fibres' ability to store water makes them functionally significant since it has a lubricating impact that affects the upper intestine's intestinal motility, postprandial satiety, and pattern of meal absorption (Aryee *et al.,* 2018). The WHC obtained in the present study is greater than the water holding capacities of 12.06 g/g and 7.53 g/g obtained in the extracted dietary fibres from outer and inner bracts of culinary banana, respectively, as reported by Begum and Deka (2019). The WHC obtained in the present study far exceed than those in high dietary fibre foods like oat bran, rice bran, soy flour and wheat bran, indicating its greater ability to entrap water within its molecular interstices (Ibrahim and Menkovska, 2022). The extracted dietary fibre had improved oil holding capacity (OHC). The hydrophobic bonding ability and large particle size of the dietary fibre molecule result in stronger molecular affinity and porosity which influences its oil holding capacity. This value is higher than the OHC of dietary fibre obtained from commercial dietary fibres (1.29 g of oil/g of dry matter) and other fibre extracts from fruits, vegetables and seaweeds ($\leq$ 2 g/g). Begum and Deka (2019) reported OHC of 5.46 g/g and 3.50 g/g in the outer and inner bracts of culinary banana, respectively, which are significantly lower than the value obtained in the present study. The improved OHC in the extracted dietary fibre from *M. bulbasiana* pseudostem is attributed to its high dietary fibre content. This property is associated with reduction in the plasma levels of cholesterol. As the dietary fibre molecules entraps oil or fat within its molecular interstices, the oil molecule remains undigested and excreted, without being absorbed in the bloodstream (Kshirsagar *et al.,* 2020). The extracted dietary fibre exhibited high swelling capacity (SC). This is in accordance with dietary fibre extracted from pineapple waste, which had a swelling capacity of 16.38 ml/g and the outer bract of culinary banana which had a swelling capacity of 15.51 ml/g. However, the swelling capacity is higher than that of the inner bract of culinary banana, which showed swelling capacity of 8.90 ml/g (Begum and Deka, 2019). The value is also higher that several prominent vegetables like peas (5.26 ml/g), chickpeas (4.28 ml/g) and edible seaweeds (5.7-10.5 ml/g) (Dhar and Deka, 2022). Another hydrating characteristic of dietary fibres that supports their use as a functional food ingredient is their swelling capacity. Afferent vagal signals of fullness are subsequently elicited by the increased swelling capacity of the extracted dietary fibre, which also slows down gastric emptying and increases stomach distension (Yadav *et al*., 2023). The extracted dietary fibre exhibited low solubility value. The solubility profile in the dietary fibre obtained in the present study is lower than soluble dietary fibre sources like oatbran (48.75), rice bran (42.75), soy flour (38.53) and wheat bran (47.41), fruits (18.23) and vegetables (16.20) (Dubey *et al.,* 2018). This is attributable to the fact that the extracted dietary fibre in the present study had higher insoluble dietary fibre content as compared to the soluble dietary fibre. The extracted dietary fibre exhibited high cation exchange capacity. The value is in accordance with the cation exchange capacity in the extracted dietary fibre from pineapple waste (6.43 mM/g) which had a high insoluble dietary fibre content of 65%. One significant physical characteristic of insoluble dietary fibres is cation-exchange capacity (CEC). It is the fibres' capacity to bind metal ions to their surface. Numerous carboxyl and hydroxyl groups can be found in cellulose, hemicellulose, and lignin, which are components of insoluble dietary fibre. These functional groups affect the dietary fibre molecule's ability to exchange cations, which is highly advantageous for controlling blood pressure and binding heavy metal ions. The build-up of heavy metal ions can cause toxicity, which is avoided by exchanging cations (He *et al.,* 2022).

The extracted dietary fibre exhibited improved glucose adsorption capacity. This indicates that the extracted dietary fibre could effectively adsorb glucose which can be attributed to the larger specific surface area, porosity and viscosity of the dietary fibre (Li *et al.,* 2022). Moreover, the enzymatic extraction of the dietary fibre increased the inter-particle void and caused exposure of side-chain groups on the dietary fibre molecule (Zhu *et al.,* 2018). According to Zheng *et al.,* 2021, the protein linked to dietary fibre also plays a role in its ability to absorb glucose, which makes it easier for it to attach to glucose through hydrogen bonds and the van der Waals force. All these mechanisms simultaneously contribute to the enhancement of glucose adsorption capacity level of the extracted dietary fibre. The improved GAC of the dietary fibre reflects its hyperglycemic potential.

The improved CAC of the extracted dietary fibre is attributable its ability bind with cholesterol (Wang *et al.,* 2020). Smaller particle sizes are produced during the extraction process, which breaks down the dietary fibre molecule's particles. The extracted dietary fiber's porous nature and small particle size allow it to bond with cholesterol (Xu *et al.,* 2015). Additionally, it has been shown that dietary fibres can bind to cholesterol in the intestinal lumen, which has an impact on the diffusion and biliary emulsification of gut epithelial cells and the lumen. This controls the blood's cholesterol levels (Benitez *et al.,* 2019).

5. Conclusion

This study has outlined the physicochemical and functional properties of the extracted dietary fibre from the pseudostem of *M. balbisiana*. RSM was used to create an "optimised model" that was used to determine the ideal experimental setup for dietary fibre extraction. While agitation had a significant but negative effect on the response under study, the extraction yield of dietary fibres rose significantly with increasing temperature and time. Under selected optimal conditions (extraction time: 41. 89 min, extraction temperature: 58.92ºC and agitation speed: 300 rpm), dietary fibre extraction yields reached 77.05%. The extracted dietary fibre showed high purity with a high insoluble dietary fibre content, particularly cellulose. Moreover, it exhibited improved physicochemical and functional properties. These findings suggest that it may have use as a nutraceutical with the ability to bind cholesterol and glucose. The possibility to use the extracted dietary fibre in food applications or as a dietary fibre supplement for the management and prevention of metabolic disorders like hyperglycemia and hypercholesterolemia is therefore encouraging.

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Conflict of interest

The authors declare no conflict of interest relevant to this article.

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