PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(sp4): 01–08
https://doi.org/10.14719/pst.5377

HORIZON
e-Publishing Group
HePG

RESEARCH ARTICLE

Optimization of microwave-assisted extraction of bajra milk using response surface methodology

Siva Sakthi T[1]*, Amutha S[2], Vijayalakshmi R[3], Gunasekaran M[4], Prabakaran K[5] & Vellaikumar S[6]

[1]Department of Food Science and Nutrition, Community Science College & Research Institute, Tamil Nadu Agricultural University, Madurai, India

[2]Department of Human Development and Family Studies, Community Science College & Research Institute, Tamil Nadu Agricultural University, Madurai, India

[3]Department of Family Resource Management and Consumer Science, Community Science College & Research Institute, Tamil Nadu Agricultural University, Madurai, India

[4]Department of Plant Breeding and Genetics, Agricultural College & Research Institute, Tamil Nadu Agricultural University, Madurai, India

[5]Department of Agricultural Statistics, Agricultural College & Research Institute, Tamil Nadu Agricultural University, Madurai, India

[6]Department of Biotechnology, Directorate of Centre for Plant Molecular Biology and Biotechnology, Tamil Nadu Agricultural University, Coimbatore, India

*Email: sivasakthit1997@gmail.com

OPEN ACCESS

ARTICLE HISTORY
Received: 30 September 2024
Accepted: 15 October 2024
Available online
Version 1.0 : 17 December 2024

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Siva Sakthi T, Amutha S, Vijayalakshmi R, Gunasekaran M, Prabakaran K, Vellaikumar S. Optimization of microwave-assisted extraction of bajra milk using response surface methodology. Plant Science Today.2024;11(sp4):01-08.
https:/doi.org/10.14719/pst.5377

Abstract

Millets, especially bajra, are known for their ability to thrive in harsh climates and resist pests. Bajra contains high nutritional values, including a high level of protein, fiber and essential minerals like iron, zinc, calcium and magnesium. Plant -based beverages such as bajra milk are becoming more popular as lactose-free, nutritious alternatives to dairy milk. Bajra milk is rich in antioxidants, phenolic acids and flavonoids, offering health benefits such as improved heart health, diabetes control and immune system support. Microwave-assisted extraction (MAE) has proven to be an energy-efficient and a sustainable technique for producing plant-based milks like bajra milk. Compared to conventional methods, MAE reduces nutrient loss, speeds up the process and improves the protein content, viscosity and sensory acceptability. Response surface methodology (RSM) was used to optimize the extraction processes, identifying ideal conditions of soaking time of 16 h, microwave time of 1.5 min and a temperature of 85℃. Under these parameters, the extraction yield was 70.23 %, with a protein content of 5.57 g/100 ml and an overall acceptability rating of 7.2. The aim of this present study is to use the RSM tool to optimize the microwave-assisted extraction of bajra milk and compare the physicochemical and nutritional properties of the conventional method and MAE, MAE bajra milk as a cost effective, ecofriendly solution for large scale plant-based milk production positioning bajra as a valuable alternative.

Keywords

bajra; microwave-assisted extraction; nutritional value; RSM

Introduction

Millets are considered promising future crops due to their resilience against insects, pests and diseases, as well as their capacity to flourish in harsh conditions, particularly in the arid and semi-arid zones of Asia and Africa (1). Millets were previously ignored due to shifts in eating habits and social status symbols, but today these nutrient-rich crops are making a powerful upturn in global agricultural production (2). Bajra (*Pennisetum glaucum*) is an important drought-resistant cereal crop. It belongs to the grass family. It is mostly cultivated in Indian subcontinent and Africa.

Bajra is being explored as a gluten-free cereal alternative for individuals with celiac diseases. Bajra, due to its rich nutritional profile it offers numerous health benefits, viz it contains high fiber content which helps to promote regular bowel movements: it has a lower glycemic index value which is beneficial for diabetic management and prevention; it has a high amount magnesium and potassium, supporting heart function, presence of lignans may reduce the cholesterol level and zinc and vitamin E content help to contribute to overall immune function (3).

Plant-based beverages, also known as non-dairy milk alternatives, are a growing trend for replacing dairy milk. They are favored by consumers who are lactose intolerant, have cow's milk allergies, are concerned about calories, have high cholesterol, or follow a vegan diet. Millet milk, which is extracted from millet grains along with water, offers a significant amount of iron, calcium and magnesium (4)

Nutritionally, bajra milk offers several advantages, including its rich content of phytochemicals such as phenolic acids and flavonoids, which have been shown to possess antioxidant and anti-inflammatory properties (5). Additionally, the high calcium and iron content in bajra milk makes it particularly suitable for addressing nutritional deficiencies in populations where dairy products may be less accessible or unsuitable due to lactose intolerance or ethical preferences (6).

Bajra milk is a non-dairy beverage that offers a nutritious, cost-effective and convenient alternative to dairy milk. The growing demand for dairy milk is challenging to meet due to factors like low milk production, limited fodder and water shortage (7). The efficient use of resources across various sectors of the food industry and the pursuit of sustainability have become increasingly important issues in recent times.

Conventional extraction methods can be more time-consuming and energy-intensive, whereas green extraction techniques such as Microwave assisted extraction methods offer a faster, more energy-efficient and also considered as an efficient alternative. Microwaves have been extensively researched in the food industry for their role in enhancing the extraction of valuable components from plant sources. (8)

The main principle behind the MAE of bajra milk relies on the use of microwave energy to heat polar molecules, particularly water within the plant matrices. In bajra milk extraction, the principle involves the rapid heating and superheating of water molecules trapped inside the bajra grains. When microwaves interact with these water molecules, they generate intense heat, causing thermal expansion and pressure buildup inside the plant cells. It leads to rupture of cell membranes and walls, allowing for the efficient release of nutrients and bioactive compounds. The efficiency of this method had the ability to selectively target polar components, reducing the need for prolonged extraction times and minimizing the use of chemicals or solvents. Microwave-assisted extraction method provides a more sustainable, energy efficient and effective approach to producing bajra milk (9).

The present study employed microwave treatment not only as a heat source but also as a method to assist in extracting bajra milk from the plant matrix. The aim of the study was to assess the impact of microwave treatment on the milk yield, protein, viscosity and overall acceptability of bajra milk and to compare the results with the conventional extraction method of bajra milk using Response Surface Methodology (RSM) as an optimizing.

Materials and Methods

Bajra (*Pennisetum glaucum*) variety was procured from the local market of Madurai, Tamil Nadu, India, in 2023-2024 cultivation year. 100 g of bajra grains were soaked for 14 to 20 h at room temperature and they were germinated for 24 h. Germinated grains were blended for 120 s in a blender. The slurry of the bajra grain samples was treated with microwave-assisted extraction method, viz., microwave time 1-3 min and microwave temperature 70- 90℃. After microwave treatment, the slurry was filtered through muslin cloth (1mm pore size). Sugar 12 % and stabilizer xanthan gums (0.5 %) are added. It was homogenized for 5 min and double pasteurized at 85℃ for 15 min and then cooled. Bajra milk was packed in a glass bottle and stored at 4℃ for further analysis. The conventional extracted bajra milk (CEM) process, which involves the same process of extracted bajra milk at 32˚C incubation temperature and without the microwave assisted treatment and considered as the control sample.

Milk yield and physicochemical properties of bajra milk

The percentage of the bajra milk yield by conventional and microwave-assisted extracted milk was calculated based on the weight of the bajra milk extracted (W1) from the weight of bajra grain slurry taken (W2) using the equation given below (Equation 1) (10).

$$\text{Extraction Yield} : \frac{W1 \times 100}{W2} \quad \ldots..(1)$$

Where, W1 represents the bajra milk and W2 bajra milk slurry

Protein content was determined by the Kjeldahl method (AOAC, 2000). The viscosity content of the bajra milk was determined by a Brookfield viscometer using spindle 61. Overall acceptability was determined by 9-point hedonic rating by semi-trained panel members.

Statistical analysis

Statistical analysis was conducted using the Design Expert (Version 14.0). Data were evaluated for significant differences ($p< 0.05$) through ANOVA (analysis of variance) with LSD (least significant difference) testing. Optimization of extraction conditions, including microwave treatments and control samples, was carried out in triplicates. The predicted experimental values were compared with the actual results to assess the acceptability and suitability of the extraction process.

Experimental Design

The experimental design for microwave-assisted bajra milk (MWAEM bajra milk) was developed using a FCCCD (Face Centered Central Composite Design) through response surface methodology (RSM). Three independent variables were studied: soaking time (X1:14 to 20 h), Microwave time (X2:1- 3 min) and microwave temperature (70- 90℃). These variables were analyzed for their effects on the dependent variables, which included milk yield (%), protein content (g/100 mL), viscosity (cP/100mL) and overall acceptability in the extracted bajra milk. The face centered central composite design included 20 experiments, as shown in Table 1. The process variables and their ranges were selected based on the preliminary analyses using different microwave times and temperatures for bajra milk extraction. The response values were derived from the average of three replicates for each experiment. The combined effects of the three independent variables and the response variables were analyzed using a quadratic model, represented by polynomial Equation (Equation 2). ANOVA was employed to calculate the linear, interaction and quadratic coefficients of the process parameters, with significance assessed at the p-<-0.05 level, as presented in Table 2.

$$Y= \beta_0 + \beta_1X_1+ \beta_2X_2+ \beta_3X_3+ \beta_{11}X_1X_1+ \beta_{22}X_2X_2+ \beta_{33}X_3X_3+ \beta_{12}X_1X_2+ \beta_{13}X_1X_3+ \beta_{23}X_2X_3 \quad \ldots\ldots (2)$$

In this context, Y represents the response factors for extraction yield, protein content, viscosity and overall acceptability from the bajra milk extract, with β0 as a constant. The coefficients β1, β2 and β3 are the linear regression coefficients, while β11, β22 and β33 represent the interaction coefficients. The quadratic coefficients are donated by β12, β13 and β23. Three-dimensional (3D) surface plots were used to illustrate the interactions between the selected dependent and independent variables. Model adequacy was evaluated using R^2, adjusted R^2, predicted R^2 and p- values. The R^2 (coefficient of determination) indicates how well the model fits the responses, with higher R^2 values signifying a better model fit (11).

Table 1. Nutritional composition of bajra grains per 100g value (19)

S.No	Parameters	Nutritional Value
1.	Ash	1.6 - 2.4 %
2.	Dry matter	88 - 91 %
3.	Crude fiber	58 - 70 %
4.	Crude protein	8.5 - 15.1 %
5.	Calcium	10 - 80 mg
6.	Magnesium	180 - 270 mg
7.	Phosphorous	450 - 990 mg
8.	Potassium	70 - 100mg
9.	Zinc	53- 70 mg
10.	Iron	70 - 180 mg

Source: Vanishree *et al.*, (2019)

Optimization of process parameters

The numerical optimization technique decreases the experimental time and effort for the investigation of the multifactor and multi-response processes. This method combined multiple responses into a single “desirability function,” which ranges from 0 (completely undesirable) to 1 (fully desirable). The independent variables were targeted to achieve minimum soaking time, microwave time and microwave temperature, while the dependent variables were optimized for maximum milk yield, protein content, viscosity and overall acceptability. The optimal microwave extraction conditions were identified through statistical analysis, obtained the highest desirability value. As a result, the optimized soaking time, microwave time and microwave temperature resulted in high milk yield, protein, viscosity and overall acceptability due to microwave-assisted extraction.

Results

Effect of microwave-assisted extraction on the yield of bajra milk

The MWAEM processing parameters, the milk yield and their interactions effect on milk yield are detailed in Table 2 and Table 3. Across the 20 treatments, soaking time of 14 h (5 treatments), 17 h (10 treatments) and 20 h (5 treatments) resulted in milk yields ranging from 69.11 to 71.27 %, 70.96 to 72.24 % and 69.34 to 71.23 %, respectively, under the selected experimental conditions of microwave time (1, 2 and 3 min) and microwave temperature (70, 80 and 90°C). The bajra milk extraction yield varied from 69.11 to 72.24 % across the 20 treatments, with an average yield of 70.68 %. The model’s F-value of 10.68 and a probability (p)< 0.0001 indicate the

Table 2. Optimization of processing parameters for Bajra milk (Traditional variety) using Microwave assisted an extraction method (MWAEM)

	Independent variable			Dependent variables			
Run	A:Soaking Time	B:Microwave Temperature	C:Microwave Time	Milk Yield[a]	Protein[a]	Viscosity[a]	Overall acceptability[a]
	Hours	Degree Celusis	Minutes	%	g/100ml	cP	
1	20	70	1	69.4	6.38	24.43	7
2	11.9546	80	2	69.75	6.34	19.78	7
3	14	90	3	71.27	6.55	22.21	7.1
4	17	80	2	71.12	6.61	23.21	7.3
5	17	96.8179	2	70.96	6.64	22.1	7.1
6	14	90	1	69.11	6.38	20.14	7
7	20	90	1	70.62	6.44	22.65	7.2
8	14	70	3	70.85	6.59	22.61	7.2
9	14	70	1	69.84	6.33	20.43	7
10	17	80	2	71.12	6.61	23.21	7.3
11	17	80	2	71.12	6.61	23.21	7.3
12	17	80	2	71.12	6.61	23.21	7.3
13	17	80	2	71.12	6.61	23.21	7.3
14	20	70	3	71.23	6.59	23.28	7.3
15	20	90	3	71.23	6.6	22.26	7.3
16	17	80	2	71.12	6.61	23.21	7.3
17	17	63.1821	2	70.54	6.48	22.58	7.1
18	17	80	3.68179	72.24	6.67	25.27	7.4
19	22.0454	80	2	69.34	6.37	20.38	7
20	17	80	0.318207	70.54	6.57	22.27	7.3

[a]Values observed in mean value of the three replicates

model's significance. Similarly, p-values for factors C and A^2 were significant (<0.005), while factors A, B, AB, AC, B^2, C^2 and BC were not significant (0.005). The regression coefficient (R^2= 0.9058) demonstrated a strong correlation between the predicted and actual values within the experimental conditions. The Predicted R^2 of 0.1934 is not as close to the Adjusted R^2 of 0.8209 as one might normally expect, i.e. the difference is more than 0.2. Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. This experiment has 12.431 indicates an adequate signal and this model can be used to navigate the design space was presented in Table 3. The three-dimensional plots in Fig. 1.a illustrate the combined impact of soaking time (16 h), microwave time (1.5 min) and microwave temperature (85℃) on the extraction yield, which is increased from 69.11 to 72.24 %. Soaking time increases milk yield of bajra grains by increasing grain hydration, which softens the cell walls and promotes the release of soluble nutrients. This process improves the extraction efficiency during grinding, leading to higher milk yield. Longer soaking also activates enzymes that further break down starches and proteins, boosting milk volume. Microwave prolonged heating may also cause changes in texture and flavour through processes like protein denaturation and the Maillard reaction. A higher microwave temperature can reduce the milk yield of bajra milk by causing protein denaturation and aggregation, which affects milk consistency and volume. So minimum microwave time and microwave temperature had higher milk yield content (12). Similar results were observed in the microwave-assisted extraction of soy milk yield, which was 4.86 kg of soymilk per kg of soybean, when compared to 3.86 kg per kg of soybean from the conventional method, resulting in a 23.92 % increase in extraction yield (10).

Effect of microwave-assisted extraction on protein content of bajra milk

The protein content of MWAEM bajra milk ranged from 6.34 to 6.67 g/100mL across 20 treatments, with an average of 6.53 g/100 mL in microwave-treated bajra milk samples. The model F-value of 10.37 indicates its significance and various factors (C, A^2) significantly affected the protein content, with p-values of 0.005. The R^2 value of 0.9032 indicates a well-fitted model. The Predicted R^2 of 0.2640 is not as close to the Adjusted R^2 of 0.8162 as one might normally expect. Adeq Precision ratio of the experiments was 12.000, which is indicating an adequate signal. This model can be used to navigate the design space. An increase in microwave time and temperature led to a reduction in the protein content from 6.67 to 6.34 g/100 mL. The three-dimensional plots in Fig. 1b illustrate the combined effects of soaking time (16 h), microwave time (1.5 min), and microwave temperature (85°C) on protein content However, at a moderate microwave time of 1.5 min and temperature of 85°C, the protein content was maximized to over 6.53 g/100 mL. Microwave-assisted extraction significantly affected the protein content of soymilk ($p < 0.05$). The protein content of soymilk extracted using the microwave-assisted method was 13.117, while compared to 7.38 in conventional soymilk, representing a notable 44.44 % increase in protein content (10). A study reported that microwave-assisted extraction methods can significantly improve the protein content in plant-based extractions due to the controlled and uniform heating process, which minimizes protein denaturation when compared to conventional heat treatments (13). Microwave-assisted extraction methods not only boost protein yield but also preserve the bioavailability of the proteins, which can be compromised in traditional extraction methods involving prolonged heat exposures (14). The use of microwave energy reduces extraction time, leading to less thermal degradation of proteins while preserving their functional properties, such as emulsifying capacity and solubility, which are crucial for the quality of plant-based milk (15).

Effect of Microwave-assisted extraction on viscosity content of the bajra milk

The experimental conditions and interactions of variables for MWAEM bajra milk was detailed in Table 2 and Table 3. The viscosity content in the MWAEM bajra milk extracts ranged from 19.78 to 25.27 cP/100 mL, with an average of 22.48 cP/100 mL. The model F-value of 11.22 indicates significant results, with only a 0.04 % chance that this large F-value could be due to noise. Prob > F values were less than 0.0500, confirming the significance of model terms. Specifically, A, C, AC and A^2 were significant model terms, while others were non-significant (0.005). The Predicted R^2 of 0.3117 is not as close to the Adjusted R^2 of 0.8288 as one might normally expect. Adeq Precision measures the signal-to-noise ratio. A ratio greater than 4 is desirable. The experiment ratio is 13.830, which indicates an adequate signal. This model can be used to navigate the design space. Fig. 1c presents the 3D plots showing the combined effects of soaking time, microwave time and microwave temperature on viscosity content. A moderate microwave time (1.5 min) and microwave temperature (85℃) had the highest viscosity content 22.76 cp/100 mL. During microwave-assisted extraction of bajra milk, the complex structures of proteins and starches were broken down, it will increase the solubility of these compounds in the liquid phase, leading to changes in the milk's texture and thickness. In particular, the energy and heat provided by microwaves alter the molecular arrangement of starch granules, promoting gelatinization which influences and increases the bajra milk viscosity. Protein also plays an important role in viscosity by forming a network that traps water and stabilizes emulsions (15). Microwave heating extraction time will influence the viscosity content of the milk; shorter extraction time prevents excessive degradation of macromolecules such as polysaccharides and protein, preserving the desired viscosity characteristics (16).

Effect of Microwave-assisted extraction on overall acceptability of the bajra milk

The MWAEM processing parameters, overall acceptability and their interaction effects are detailed in Table 2 and Table 3. The overall acceptability of MWAEM bajra milk varied between 7 to 7.4 across 20 treatments, with an average of 7.19 in microwave-treated samples. The model F-value of 14.30 highlights its significance, with factors A, C, A^2 and B^2 significantly influencing overall acceptability ($p = 0.005$). The R^2 value of 0.9279 indicates a well-fitted model, though the predicted R^2 0.4469 is not as close to the Adjusted R^2 of 0.8630 as typically expected. The adequate precision ratio of 14.43 suggests a strong signal, making this model suitable for navigating the design space.

The 3D plots in Fig. 1d show the combined effects of soaking time, microwave time and microwave temperature on overall acceptability. As microwave time and temperature increased, overall acceptability reduced from 7.4 to 7.1. However, with a moderate microwave time of 1.5 min and a temperature of 85°C, overall acceptability was maximized to over 7.4. Microwave-assisted extraction (MAE) influences the overall acceptability of bajra milk through several key factors, including visual appeal, flavour, texture and nutritional quality. MAE accelerates the release of volatile compounds and affects lipid oxidation: it will be altering the flavour profile. It may enhance natural flavors but could also lead to undesirable off-flavours if overheating occurs, particularly from Maillard reactions or protein denaturation. Excessive heating may denature proteins, resulting in a gritty texture, negatively affecting overall acceptability. MAE can enhance the natural flavors by efficiently releasing flavor compounds; proper regulation of microwave settings is crucial to avoid the development of undesirable flavors caused by excessive heating (17). Grain-based milk alternatives have shown that MAE improves texture by optimizing protein extraction and reducing grittiness (17).

Optimization and validation of extraction process

The experiment yielded a desirability value of 1.000, which was achieved under the conditions of soaking time (16 h), microwave time (1.5 min) and microwave temperature (85 °C). Under these optimized conditions, the response showed an average extraction yield of 70.23 %, protein content of 5.57 g/100 ml, viscosity of 22.24 cP/100 mL and overall acceptability of 7.2. Bajra milk was extracted under these conditions and validated through regression analysis, as shown in Fig. 1. The observed values closely matched the predicted values, with a strong correlation ($R^2 > 90\%$) for all responses.

Comparison of physico-chemical properties of microwave-assisted extraction and control bajra milk

The optimized MWAEM bajra milk was experimentally tested and its physicochemical properties were compared with CEM (Table 4). A significant improvement ($p < 0.05$) was observed in the physicochemical properties of the bajra milk extracted using optimized microwave-assisted extraction. Bajra milk extraction increased by 4.50 %, from 135.12 ± 0.238 to 140.26 ± 2.31. similarly, viscosity 18.97 %, TSS 8 %, protein 7.73 % compared to the control sample. Rapid and uniform heating

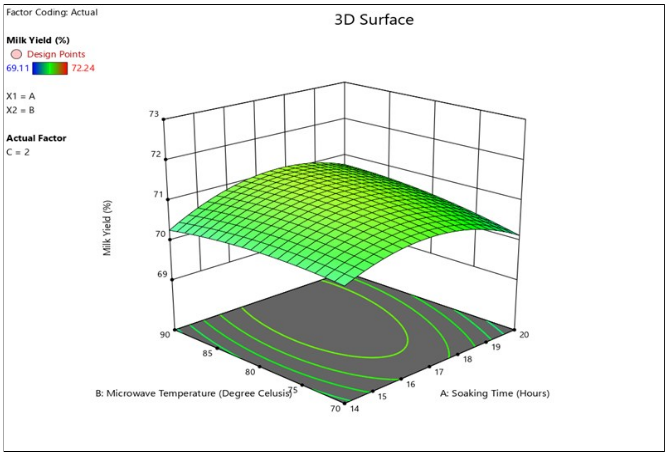

Fig 1.a. The three-dimensional plots illustrate the combined effects of soaking time (16 h), microwave time (1.5 min) and microwave temperature (85℃) on Milk yield content.

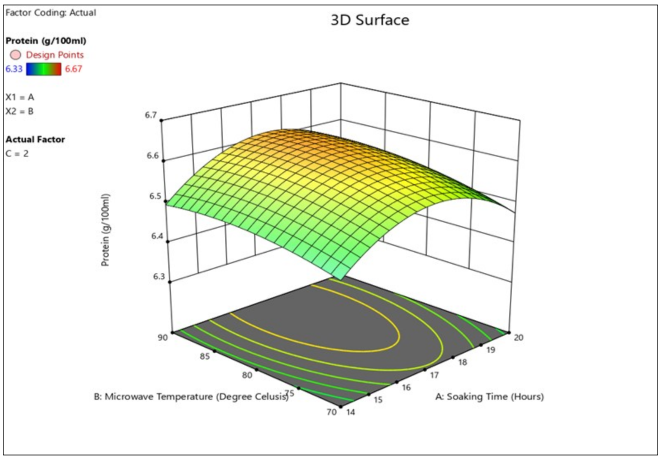

Fig 1.b. The three-dimensional plots illustrate the combined effects of soaking time (16 h), microwave time (1.5 min) and microwave temperature (85℃) on protein content.

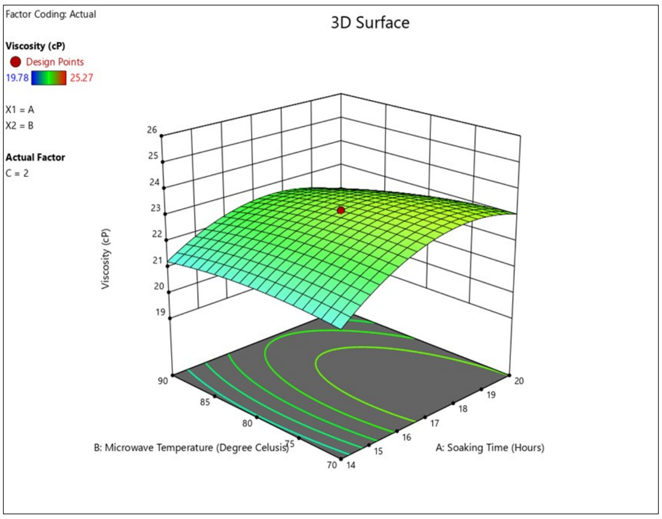

Fig 1.c. The three-dimensional plots illustrate the combined effects of soaking time (16 h), microwave time (1.5 min) and microwave temperature (85℃) on viscosity content.

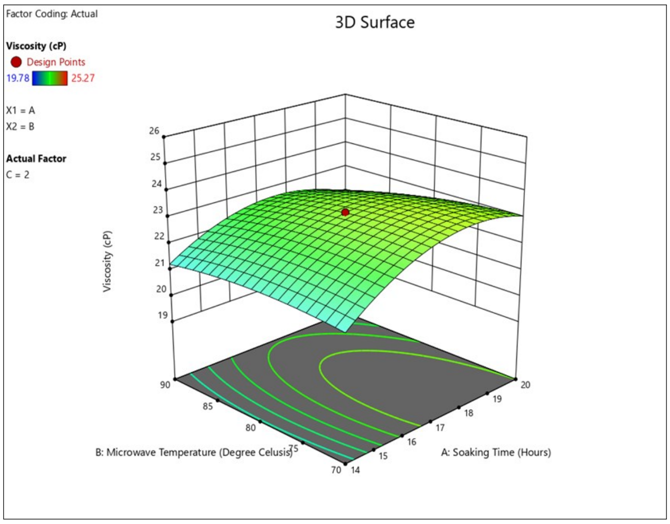

Fig 1.d. The three-dimensional plots illustrate the combined effects of soaking time (16 h), microwave time (1.5 min) and microwave temperature (85℃) on overall acceptability .

Interaction between A (Soaking Time) and B (Microwave Time) at C (Microwave Temperature)

Fig. 1 Response Surface Plats for Milk yield, protein, viscosity and overall acceptability content from MWAEM Bajra (Traditional variety) milk.

Table 3. Regression coefficients and ANOVA estimated for extraction yield, protein, viscosity and overall acceptability of Microwave- assisted extraction method (MWAEM)- Bajra Traditional variety milk

Factor	DF	Extraction yield (%)				Protein (g/100 mL)				Viscosity (cP/100 mL)				Overall acceptability			
		Coefficient Estimate	Sum of squares	F value	*p* - value	Coefficient Estimate	Sum of squares	F value	*p* - value	Coefficient Estimate	Sum of squares	F value	*p* - value	Coefficient Estimate	Sum of squares	F value	*p* - value
Model	9	71.12	11.02	10.68	0.0005	6.61	0.2181	10.37	0.0005	23.20	33.82	11.22	0.0004	7.30	0.3322	14.30	0.0001
Linear																	
A	1	0.0528	0.0380	0.3314	0.5775	0.0154	0.0032	1.39	0.2660	0.6033	4.97	14.84	0.0032	0.0366	0.0183	7.09	0.0238
B	1	0.1184	0.1913	1.67	0.2255	0.0256	0.0089	3.82	0.0792	-0.3147	1.35	4.04	0.0723	0.0073	0.0007	0.2837	0.6059
C	1	0.6201	5.25	45.80	< 0.0001	0.0709	0.0686	29.38	0.0003	0.5679	4.40	13.15	0.0046	0.0636	0.0552	21.39	0.0009
Interactions																	
AB	1	0.1912	0.2926	2.55	0.1413	0.0075	0.0004	0.1926	0.6701	-0.2637	0.5565	1.66	0.2264	0.0375	0.0113	4.36	0.0634
AC	1	-0.0913	0.0666	0.5809	0.4636	-0.0075	0.0005	0.1926	0.6701	-0.7237	4.19	12.51	0.0054	0.0125	0.0013	0.4843	0.5023
BC	1	-0.0088	0.0006	0.0053	0.9432	-0.0175	0.0025	1.05	0.3300	0.0813	0.0528	0.1577	0.6996	-0.0375	0.0112	4.36	0.0634
Quadratic																	
A2	1	-0.5746	4.76	41.49	< 0.0001	-0.0951	0.1302	55.73	< 0.0001	-1.05	15.96	47.64	< 0.0001	-0.1068	0.1643	63.67	< 0.0001
B^2	1	-0.1486	0.3180	2.77	0.1268	-0.0226	0.0073	3.14	0.1067	-0.2533	0.9243	2.76	0.1276	-0.0714	0.0735	28.49	0.0003
C^2	1	0.0777	0.0871	0.7592	0.4040	-0.0014	0.0000	0.0114	0.9170	0.2523	0.9175	2.74	0.1289	0.0170	0.0041	1.61	0.2337
Lack of fit			1.15				0.0234				3.35				0.0258		
Mean±SD			70.68±0.33				6.53±0.04				22.48±0.57				7.19±0.05		
R^2			0.9058				0.9032				0.9099				0.9279		
Adjusted R^2			0.8209				0.8162				0.8288				0.8630		
Predicted R^2			0.1934				0.2640				0.3117				0.4469		
CV			0.4791				0.7403				2.57				0.7066		

The p values indicated that to check the significance level of each coefficient. The p values <0.005 are indicated as significant effect of independent factor on response variable at 5 %, DF-Degree of Freedom; SD-Standard Deviation; CV-Critical Value.

Table 4: Comparison of physicochemical properties of microwave assisted extraction and control bajra milk

Characteristics		CEM[a]	MWAEM[b]	P value	% change[c]
	L	135.12 ±0.238	140.26±2.31	0.003	3.7
Colour value	a	3.26±0.053	4.87±0.159	0.002	0.49
	b	28.34±0.424	28.26±0.634	0.003	0.28
Viscosity (cP)		21.76±0.710	25.89±0.757	0.835	18.97
Extraction yield (%)		67.2±2.011	70.23±2.150	0.005	4.50
pH		5.5±0.116	5.25±0.153	0.038	-4.54
TSS (°Bx)		5.00±0.040	5.4±0.033	0.723	8
Acidity (%)		0.048±0.011	0.039±0.001	0.000	18.75
Crude protein (g/100ml)		5.17±0.147	5.57±0.079	0.001	7.73
Overall acceptability		7±0.152	7.4±0.050	0.002	5.71

Note: values mentioned as mean ± standard deviation of three replicate analysis (n=3)

The treatments are significantly differed at p<0.05

Abbreviations: CEM, conventional Extraction Method, MWAEM, Microwave Assisted Extraction Method

[a] Control without microwave treatment

[b] optimized value obtained from the soaking time (16 h), microwave time (1.5 min) and microwave temperature (85 °C).

[c] values are approximate and not mentioned with standard deviation

[d]Bx- Brix, cP - Centipose

provided by microwaves, which effectively disrupts cell walls and enhances the release of soluble solids and proteins and intense localized heating improves the solubilization and may promote the formation of protein complexes, contributing to the higher viscosity observed in the MWAEM bajra milk. While color L*, a* and b* values are highly significant, may be enhanced by Maillard reactions and caramelization from rapid heating, and it will intensify the colour of the material. Conventional methods require longer extraction time and results in lower extraction efficiency due to slower heat transfer and incomplete cell wall. MAE increases the yield of phenolic compounds and proteins, resulting in higher nutritional quality compared to conventional extraction. Conventional extraction may result in a thinner or less uniform texture due to incomplete protein extraction. The longer processing time could affect the overall mouthfeel of the product. Plant-based milk has shown that MAE produces a thicker, creamier texture compared to conventional methods. Conventional methods generally maintain the natural pH levels of bajra milk, as the slower heating process minimizes rapid chemical reactions that might alter acidity. Microwave treatment can cause slight alterations in pH due to the formation of new compounds during the Maillard reaction induced by rapid heating (18).

Conclusion

Microwave-assisted extraction of bajra milk has demonstrated significant potential in improving the quality of the milk. Through optimization using RSM (Response Surface Methodology), key process parameters such as microwave time, microwave temperature and soaking time of the bajra grains were successfully optimized. The RSM model provided a reliable prediction of optimal conditions, resulting in optimized process conditions of microwave treatment that had better nutrient retention, improved functional properties and better sensory acceptability. Prolonged microwave treatment reduces nutritional value, functional properties and sensory acceptability. Optimized value obtained from the soaking time (16 h), microwave time (1.5 min) and microwave temperature (85 °C). Under these optimized conditions, the response showed an average extraction yield of 70.23 %, protein content of 5.57 g/100 mL, viscosity of 22.24 cP/100 mL and overall acceptability of 7.2. MAE of bajra milk is superior to conventional methods, the rapid and uniform heating in MAE preserves heat sensitive compounds and reduces processing time, minimizing nutrient loss. While compared to conventional method of bajra milk extraction, MAE has reduced processing time and energy efficiency, make it an eco-friendly and cost-effective method for industrial-scale production of plant-based milks. This approach highlights the potential of using MAE coupled with RSM to streamline and innovate plant-based milk processing, with bajra as a sustainable alternative source.

Acknowledgements

We would like to express our sincere gratitude to DST- SHRI and all those who contributed to the completion of this review article. Firstly, we extend our appreciation to the authors whose insightful research formed the foundation of this work. Their dedication to advancing knowledge in the field has been invaluable

Authors' contributions

SST and AS contributed in the conceptualization, data curation and formal analysis and investigation of the study.ST prepared the original draft, ST, AS, VR, GM, PK and VS contributed in methodology. ST, AS, VR, GM, PK and VS provided the resource for the study. ST, AS, VR, GM, PK and VS helped in investigation and writing. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Babele PK, Kudapa H, Singh Y, Varshney RK, Kumar A. Mainstreaming orphan millets for advancing climate smart agriculture to secure nutrition and health. Frontiers in Plant Science. 2022;13. https://doi.org/10.3389/fpls.2022.902536
2. Gessaroli M, Frazzoni L, Sikandar U, Bronzetti G, Pession A, et al. Nutrient intakes in adult and pediatric coeliac disease patients on gluten-free diet: a systematic review and meta-analysis. European Journal of Clinical Nutrition. 2023;77(8):784-93. https://doi.org/10.1038/s41430-023-01280-0
3. Yadav S, Singh HC, Singh DR. Nutritional quality of millets and their value-added products with the potential health benefits: A review. Int. J. Curr. Microbiol. App. Sci. 2021;10(10):163-75. https://doi.org/10.20546/ijcmas.2021.1010.019
4. Kumar A, Kaur A, Tomer V, Rasane P, Gupta K. Development of nutri cereals and milk-based beverage: Process optimization and validation of improved nutritional properties. Journal of Food Process Engineering. 2020;43(1). https://doi.org/10.1111/jfpe.13025
5. Bhati KT, Kumar S, Haileslassie A, Whitbread AM. Assessment of agricultural technologies for dryland systems in South Asia: A case study of Western Rajasthan, India. [monograph on the Internet]. Hyderabad, India: ICRISAT; 2017. Available from: http://oar.icrisat.org/id/eprint/10837
6. Nambiar VS, Dhaduk JJ, Sareen N, Shahu T, Desai R. Potential functional implications of pearl millet (*Pennisetum glaucum*) in health and disease. Journal of Applied Pharmaceutical Science. 2011:62-67.
7. USDA Foreign Agricultural Service. India: Dairy and Products Annual. GAIN: 2017. IN6126.
8. Tsubaki S, Onda A, Hiraoka M, Fujii S, Azuma JI, Wada Y. Microwave-assisted water extraction of carbohydrates from unutilized biomass: water extraction of bioactive compounds, from plants to drug development, Elsevier. 2017;199-219. https://doi.org/10.1016/B978-0-12-809380-1.00007-3
9. Flórez N, Conde E, Domínguez H. Microwave assisted water extraction of plant compounds. Journal of Chemical Technology & Biotechnology. 2015;90(4):590-607. https://doi.org/10.1002/jctb.4519
10. Varghese T, Pare A. Effect of microwave assisted extraction on yield and protein characteristics of soymilk. Journal of Food Engineering. 2019; 262:92-9. https://doi.org/10.1016/j.jfoodeng.2019.05.020
11. Mushtaq M, Sultana B, Anwar F, Adnan A, Rizvi SS. Enzyme-assisted supercritical fluid extraction of phenolic antioxidants from pomegranate peel. The Journal of Supercritical Fluids. 2015; 104:122-31. https://doi.org/10.1016/j.supflu.2015.05.020
12. Smith NW, Dave AC, Hill JP, McNabb WC. Nutritional assessment of plant-based beverages in comparison to bovine milk. Frontiers in Nutrition. 2022;9. https://doi.org/10.3389/fnut.2022.957486
13. Kratchanova M, Pavlova E, Panchev I. The effect of microwave heating of fresh orange peels on the fruit tissue and quality of extracted pectin. Carbohydrate Polymers. 2004;56(2):181-85. https://doi.org/10.1016/j.carbpol.2004.01.009
14. Xiang S, Zou H, Liu Y, Ruan R. Effects of microwave heating on the protein structure, digestion properties and Maillard products of gluten. Journal of Food Science and Technology. 2020;57:2139-49. https://doi.org/10.1007/s13197-020-04249-0
15. Rajpurohit B, Li Y. Overview on pulse proteins for future foods: Ingredient development and novel applications. Journal of Future Foods. 2023;3(4):340-56. https://doi.org/10.1016/j.jfutfo.2023.03.005
16. Chen X, Yang J, Shen M, Chen Y, Yu Q, Xie J. Structure, function and advance application of microwave-treated polysaccharide: A review. Trends in Food Science & Technology. 2022;123:198-209. https://doi.org/10.1016/j.tifs.2022.03.016
17. Aourach M, González-de-Peredo AV, Vázquez-Espinosa M, Essalmani H, et al. Optimization and comparison of ultrasound and microwave-assisted extraction of phenolic compounds from cotton-lavender (*Santolina chamaecyparissus* L.). Agronomy. 2021;11(1):84. https://doi.org/10.3390/agronomy11010084
18. Dhar R, Chakraborty S. Effect of continuous microwave processing on enzymes and quality attributes of bael beverage. Food Chemistry. 2024;453. https://doi.org/10.1016/j.foodchem.2024.139621
19. Vanishree S, Kammar MR, Nidoni U. Development and evaluation of pearl millet based novel health drink. Advances in Life Sciences. 2016;5(13):5483-86.