Research Article

Response Surface Modelling and Analysis for Ball Milling of Coriander Seeds

Sivamani Selvaraju, Naveen Prasad Balakrishna Pillai Sankari*, Halima Khalid Mohammed Al-Shukaili, Mohammed Ahmed Al-Mashikhi and Salim Said Salim Shaaban Bait Jamil

College of Engineering and Technology, Engineering Department, University of Technology and Applied Sciences, Salalah, Oman.

Abstract | Ball milling technique that uses a rolling mill equipped with a steel ball to grind, blend, and refine various foods for different flavor, taste, and nutritional qualities. This method can be applied to a variety of food products including grains, vegetables, spices, fruits and nuts. The main objective of a circular feed mill is to obtain fine and uniform particle sizes, thus improving product quality. The aim of the study is to obtain the minimum particle size by controlling rotation time, spherical rotation speed, and feed rate. Food scientists and manufacturers can adjust conditions if they are used to produce specific characteristics, such as softness or more pronounced sweetness. In addition to studying one variable at a time, the response surface method is used to generate relative models of the independent and dependent variables. In conclusion, it is a promising technique for the food industry, providing an efficient and versatile way to improve the sensory properties and the value of nutritional foods.

Received | January 17, 2024; **Accepted** | December 04, 2024; **Published** | December 26, 2024
***Correspondence** | Naveen Prasad Balakrishna Pillai Sankari, College of Engineering and Technology, Engineering Department, University of Technology and Applied Sciences, Salalah, Oman; **Email:** bsnaveenprasad@gmail.com
Citation | Selvaraju, S., N.B.P.B. Sankari, H.K.M. Al-Shukaili, M.A. Al-Mashikhi and S.S.S.S.B. Jamil. 2024. Response surface modelling and analysis for ball milling of coriander seeds. *Pakistan Journal of Agricultural Research,* 37(4): 384-392.
DOI | https://dx.doi.org/10.17582/journal.pjar/2024/37.4.384.392
Keywords | Milling time, Particle size, Rotational speed, Ball mill, Coriander seeds, Response surface method

Introduction

Food production plays an important role in preservation of perishables, food safety, reducing the risk of food borne diseases and mitigating food waste. It expedites and simplifies food production and accommodates the fast-paced lifestyles of modern consumers and also grows the nutritional value of some foods through preservation methods, which helps prevent nutritional deficiencies in populations Industries contribute significantly to economically by creating jobs, supporting agriculture, facilitating international trade by exporting fresh foods. Also, food processing provides fresh, complementary foods and flavours for various culinary ingredients and cultures change around the world It is important to select appropriate for growth and nutrient intake (Lamsal *et al*., 2019).

There are some advanced grinding techniques, such as cryogenic grinding, ultrasonic milling, and jet milling, especially in the perfume industry where valuable products can be high. For example, they include roasted coriander, chilli etc., in a larger chamber with 2 pin rotors without a strainer. The spice market still uses stones to grind ground mustard in a vinegar solution known as sour grapes. Commercial applications continue to employ this primitive yet highly effective method. Twelve hours are sufficient to grind one ton of grain using dozens of wheels in series, two of which have a diameter of 30 cm (Shin *et al*., 2013).

A ball mill is used to produce foods that need to be ground to submicron size such as chocolate, cheese, almonds, and so on. Impact mills make it easy to change the texture of powdered foods. Frequently, spices are pulverized in these mills. Also, feldspar for pottery, coal, pigment and mining ore are all ground in a round mill. It can be made wet or dry, but it doesn't need much speed when it's fried. Rubber balls are used over wide areas, mixing with explosives (Shi and Xie, 2015).

Ball milling is one of the promising methods for extracting flavor and nutrients from food ingredients. It is an industrial process to compact (reduce the size) of various materials, finding applications in many industries such as pharmaceutical, materials and food processing. Rotary drums or ball mills can be used industrially for particle reduction largely to fine powder production. It has been widely used in many applications such as size reduction, mixing and blending in various industries including food processing. One common method of reducing particulate matter is ball milling. It can be made by reducing the amount of sugar crystals, grinding rice flour, or processing it into ground spices. The quality and distribution of milled products with respect to particle size were assessed through an investigation into the effects of various milling parameters, including round size, speed, and duration (Gao *et al*., 2020). In recent years, researchers have undertaken an examination of the application of circular milling as a viable and effective method for replacing flavors and nutrients in plant-based products, including coriander seeds.

The particle size of rice grains is strongly influenced by the quality of rice milled and its consumption. The physicochemical properties of ground grains of different sizes after milling and hammering were evaluated. These properties include moisture content, antioxidant activity, nutritional value and microstructural properties. During the spherical process, insoluble food fibers were converted into soluble food fibers in the roasted rice. As particle size decreased, porosity increased, porosity decreased, and incorporation into hydrophilic groups led to disruption of the cellulose structure, according to SEM, FTIR and X-ray diffraction revealed (Cao *et al*., 2021).

International culinary traditions make extensive use of the aromatic herb *Coriandrum sativum*. Citrusy, earthy, and subtly spicy in flavor and fragrance, the seed leaves of this plant are highly valued. Aside from their potential nutritional and health benefits, coriander seeds are also abundant in metabolites, antioxidants, and essential oils, which contribute to their flavour Maroufi *et al*. (2010) and tradition extraction methods, such as steam and chemical solvents, can be difficult to extract and preserve extract, volatile degradation products and oxidizing nutrients. As an alternative to circular spinning, which can result in splitting, this problem can be avoided by decreasing the quantity of seeds with negligible effect on their nutritional value and flavour (Chemat *et al*., 2020; Baig *et al*., 2023).

The response surface method is a statistical technique used to optimize and model complex systems. It is commonly employed in fields such as engineering, manufacturing, and design. It involves creating a mathematical model that relates the input variables of a system to its output response. Also, it helps determine the relationship between the factors and the response by conducting experiments and collecting data at different factor levels. This information is then used to optimize the performance of system. The technique uses a combination of experimental design, regression analysis, and graphical analysis to build the model. This model could be used to predict responses and identify optimal factor settings that maximize or minimize the desired outcome. It is particularly useful when the relationship between factors and responses is nonlinear or when there are interactions between factors. Researchers and engineers could efficiently explore the design space, reduce costs, and improve the performance of their systems by using response surface method (RSM).

The literature review highlights the advantages and benefits of rolling balls for the food industry. Consumption accuracy and results can vary significantly depending on the feed type, milling parameters, and desired product properties (Gaikwad *et al*., 2023). Scholars are researching and refining circular grinding methods for food prevention to meet dynamic needs Since there is limited literature available on circular grinding of coriander seeds (Saxena et al., 2018), therefore this study explores the use of spherical milling to enhance flavor and nutritional value to subject coriander seeds to controlled mechanical forces that damage their cell structure, and release valuable compounds This method has a potential to enhance evaluating the nutritional value and overall sensory profile of products containing coriander. The objectives of this study were to determine the effect of feed rate, rotational speed and milling time on average particle size in the ball milling of coriander seeds using response surface method.

Materials and Methods

Materials

Raw material, coriander seeds, was purchased from the local market in Salalah, Oman. A ball mill from Armfield Solids Handling Studies (CEN-MKII) was used in this experiment.

Ball milling of coriander seeds

It is securely and evenly secured to the flat surface of the ball mill. A suitable quantity of grinding agent (alumina pellets) and coriander seeds (25, 50 and 75 g, respectively) were inserted into the mill in accordance with the mill's design and the particular application. The control panel was then adjusted to the desired rotational speed of the mill (5, 7.5, 10 rpm). By sustaining the velocity below the critical speed, which is reached when the gravitational force opposes the centrifugal force on the ball, this mechanism effectively averts excessive wheel deterioration. The grinding process takes between ten and forty minutes. It started at the ball mill and made it work. As the mill rotates, the inner ball of alumina is raised by centrifugal force to a height on the rising side of the mill shaft.

Upon reaching the uppermost region of the shell, the coriander seeds undergo a pulverizing and startling operation. Consequences of repeated collisions and friction between the alumina ball and the seed include the pulverizing and reduction in size of the seed particles. The operation of the mill was observed, encompassing the milling process's advancement and the dimensions of the material that was processed. By adjusting the rotational speed, the desired particulate size was achieved. Samples of the material were collected every ten minutes in order to assess particle size and quality. Ball mill was halted when grinding was finished or the specified particle size was achieved.

RSM model for ball milling of coriander seeds using BBD

The RSM was employed in the present study due to its efficiency in reducing the number of experiments, thereby minimizing errors. Design-expert 13.0.4.0 (64-bit) was used to perform RSM design. In the experimental design, effect of ball milling on coriander seeds was investigated under different conditions of mass of feed, speed of mill, and time of milling as independent variables and particle size as a dependent variable. The choice of box-behnken design (BBD) based on response surface method was opted in this study. Furthermore, BBD was selected to reduce the number of levels to three for each factor, as opposed to other RSM designs require five levels. This approach streamlines the experimentation process while still allowing to obtain valuable insights and optimize the variables effectively. The BBD requires a total number of trials equal to 2f(f-1) + CP, where CP represents the number of centre points, and f is the number of independent variables. In the case of BBD for three independent variables with three centre points, it necessitates a total of 15 experiments. The advantage of BBD is that it enables the simultaneous alteration of three variables. This approach allows for the examination of how interactions between these variables affect the outcomes, providing valuable insights into the relationship between the independent and dependent variables. The coded values are determined using Equation 1.

$$y_c = (y_a - y)/\Delta y) \quad ....(1)$$

Where, y_a is the actual value, y_c is the coded value, y is the mean value and Δy is the difference between any two values of independent variables. Equation 2 provides an overall quadratic expression that relates dependent and independent components:

$$Y = a_o + a_1A + a_2B + a_3C + a_4A.B + a_5C.B + a_6A.C + a_7A^2 + a_8B^2 + a_9C^2 \quad ...(2)$$

Where; Y is particle size after milling, A is mass of feed, B is rotational speed of ball mill, and C is the time of milling, a_0 is intercept, a_1, a_2 and a_3 are linear coefficients for mass of feed, rotational speed of ball mill and time of milling, respectively, a_4, a_5 and a_6 are interactive coefficient between mass of feed, rotational speed of ball mill and time of milling, and a_7, a_8 and a_9 are quadratic coefficients for mass of feed, rotational speed of ball mill and time of milling, respectively. The principle of least squares (PLS) states that the sum of the squares of the residue is zero. If Equation 2 is modelled as a matrix, then it is represented in Equation 3 as follows:

$$AX = B \quad ....(3)$$

Since number of experiments (15) exceeds number of unknowns (10) in Equation 2, according to the PLS, the coefficient matrix is given in Equation 4 as:

$$X=(A^T.A)^{-1}.(A^T.B) \quad ...(4)$$

Where; A represents input matrix, X is coefficient matrix, and B represents output matrix. Equation 4 was utilized to determine the coefficient matrix X. The model terms were assessed for statistical significance using p-value, which should be less than 0.05. The goodness of fit of the model is revealed from the determination coefficient. Three-dimensional surface plots were used to examine the interaction between the numerical independent variables on response variable (Gharibzadeh *et al*., 2016; Sharifi *et al*., 2019; Moghaddam *et al*., 2019; Li *et al*., 2019; Nam *et al*., 2018; Sivamani *et al*., 2022; Banerjee *et al*., 2023; Selvaraju *et al*., 2023).

Results and Discussion

Ball milling of coriander seeds

Coriandrum sativum seeds are distinguished by their appearance and texture. Coriander seeds contain an oily, viscous substance. Hard and resistant to manual breaking. Typically, coriander seeds have a silky, fine exterior. Although some seeds have long, smooth spots or thin lines, they are not particularly noticeable. Coriander seeds have a distinct citrus aroma and a texture that is earthy and faintly sweet. It generates an aromatic, warm, and mildly spicy flavor with citrus undertones when crushed or ground. Aroma and flavor are imparted to breads, stews, curries, and soups with coriander seeds. The reduced energy required to ground coriander seeds in a round mill is attributed to their shape and texture.

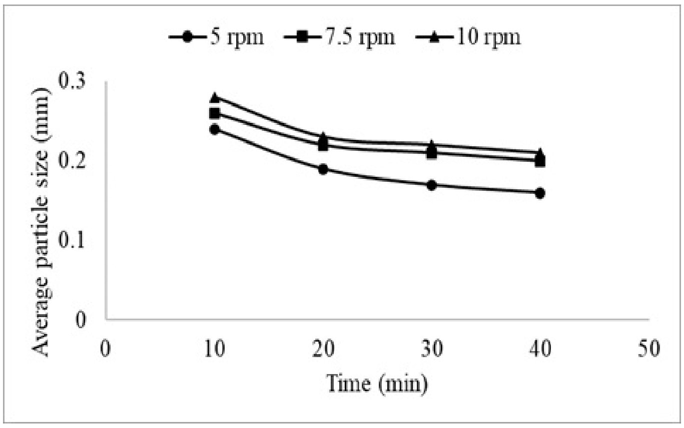

Figure 1: *Milling time effect on particle average size at different rotational speeds (5, 7.5 and 10 rpm) for 25 g feed.*

For 25 g of feed, Figure 1 illustrates the impact of milling time on the particle average size of coriander seeds milled at 5, 7.5, and 10 rpm. After ten minutes, the average particulate size decreases from two to 0.24 mm; after twenty minutes, the reduction to 0.19 mm is statistically significant. Subsequently, the particle size exhibits a near-constant value of 0.17 and 0.16 mm after 30 and 40 minutes, respectively, when 5 rpm is utilized. At 7.5 rpm, the particle average size decreases from 2 to 0.26 mm within 10 minutes, and further diminishes by 0.22 mm after 20 minutes. After thirty and forty minutes, the particulate size approaches a near-constant value of 0.21 and 0.2 mm, respectively. In a similar fashion, the average particulate size decreases from 2 to 0.28 mm within ten minutes, and further diminishes by 0.23 mm after twenty minutes at ten revolutions per minute. After thirty and forty minutes, the particulate size approaches a near-constant value of 0.22 and 0.21 mm, respectively. From the experimental findings, it was observed that the optimal rotational speed of a ball mill for pulverizing coriander seeds is 5 rpm for duration of 20 minutes (Barnwal *et al*., 2014; Aradwad *et al*., 2021).

The impact of milling time on the particle average size of coriander seeds at different rotational rates of 5, 7.5, and 10 revolutions per minute is illustrated in Figure 2 for a 50 g feed. Prior to milling, coriander seeds have a diameter of 2 mm. As a result, the mean particle size decreases from 2 to 0.25 mm within a duration of 10 minutes. Subsequently, the reduction reaches a significance level of 0.22 mm after 20 minutes. The particulate size approaches a state of near-constant variation at 0.21 and 0.2 mm, respectively, following 30 and 40 minutes of 5 rpm operation. At 7.5 revolutions per minute, the mean particulate size decreases from 2 to 0.26 mm within ten minutes, and further diminishes by 0.24 mm after twenty minutes. After thirty and forty minutes, the particulate size approaches a near-constant value of 0.22 and 0.21 mm, respectively. In a similar fashion, the mean particulate size decreases from 2 to 0.29 mm within a span of 10 minutes, with a further significant reduction of 0.26 mm occurring after 20 minutes. After 30 and 40 minutes at 10 revolutions per minute, the particle size approaches a near-constant value of 0.25 and 0.24 mm, alike. From the experimental findings, it was identified that the optimal rotational speed of a ball mill for pulverizing coriander seeds is 5 rpm for duration of 20 minutes (Barnwal *et al*., 2014; Aradwad *et al*., 2021).

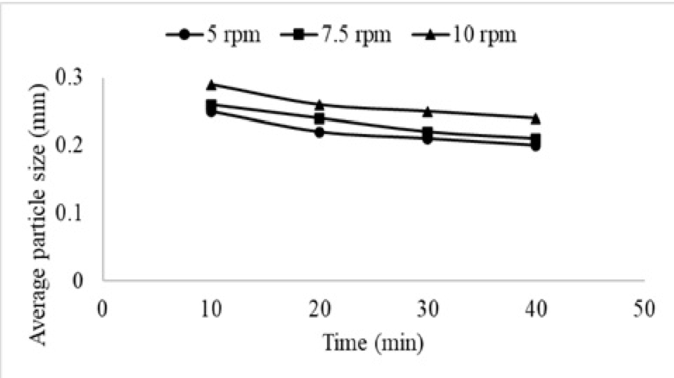

Figure 2: *Milling time effect on particle average size of coriander seeds at various rotational speed (5, 7.5 and 10 rpm) for 50 g feed.*

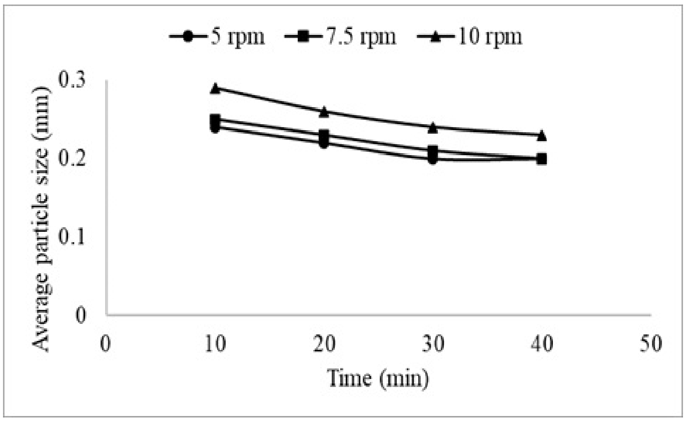

Figure 3: *Milling time effect on particle average size at different rotational speeds (5, 7.5 and 10 rpm) for 75 g feed.*

The milling time impact on the particle average size of coriander seeds at different rotational rates of 5, 7.5, and 10 revolutions per minute is illustrated in Figure 3 for a 75 g feed. Prior to milling, coriander seeds have a diameter of 2 mm. Consequently, the mean particle size decreases from 2 to 0.24 mm within a duration of 10 minutes. Subsequently, the reduction reaches a significance level of 0.22 mm after 20 minutes. The particle size approaches a near-constant value of 0.2 mm each following 30 and 40 minutes of operation at 5 rpm. The average particle size decreases from 2 to 0.25 mm after 10 minutes at 7.5 revolutions per minute; after 20 minutes, the decrease in particle size to 0.23 mm is statistically significant. After thirty and forty minutes, the particulate size approaches a near-constant value of 0.21 and 0.2 mm, respectively. In a similar fashion, the mean particulate size decreases from 2 to 0.29 mm within a span of 10 minutes, with a further significant reduction of 0.26 mm occurring after 20 minutes. The particulate size approaches a state of near-constant variation at 0.24 and 0.23 mm, respectively, following 30 and 40 minutes of operation at 10 rpm. From the experimental findings, it can be deduced that the optimal rotational speed of a ball mill for pulverizing coriander seeds is 5 rpm for a duration of 20 minutes (Barnwal *et al*., 2014; Aradwad *et al*., 2021). Regarding the mass of the material, the minimum average particle size observed is 25 grams.

RSM model for ball milling of coriander seeds using BBD

Table 1 shows the variables and levels used to mill *Coriander sativum* seeds. Table 2 shows the BBD matrix of 15 experiments for ball milling of *Coriander sativum*. All the experiments were performed in triplicate and the mean value was taken as a response. Then, the actual values from each experiment were substituted to the quadratic model, Equation 4, to calculate the coefficients. After fitting coefficients to Equations 4, 5 was obtained as follows:

$$Y = 0.19 + 0.0025A + 0.012B - 0.0065C - 1.7 \times 10^{-18} A.B + 2 \times 10^{-5} A.C + 1.39 \times 10^{-19} B.C - 2.7 \times 10^{-5} A^2 - 2.67 \times 10^{-4} B^2 + 8.3 \times 10^{-5} C^2 \quad ....(5)$$

Table 1: *Variables and levels used for ball milling of coriander sativum seeds.*

Variable	Unit	Symbol	Levels		
			Low (-1)	Middle (0)	High (+1)
Mass of feed	g	A	25	50	75
Rotational speed of ball mill	rpm	B	5	7.5	10
Time of milling	min	C	10	20	30

In general, an increase in negative coefficient tends to decrease the response and vice versa. Similarly, a decline in positive coefficient tends to diminish the dependent factor and vice versa. Hence, in Equation 5, the signs of linear and quadratic terms involving mass of feed, rotational speed of ball mill, and time milling are in opposite signs. The linear terms of mass of feed and rotational speed are positive whereas time of milling is negative, meaning that particle size is directly proportional to mass of feed and rotational speed and has inverse effect on time of milling. The change in sign is observed only in interactive term involving time of milling. Hence, time of milling was found to be the significant factor followed by rotational speed and mass of feed (Zhang *et al.*, 2021).

Table 2: *BBD matrix of 15 experiments for ball milling of C. sativum.*

Std	Run	Independent factors			Response
		A: Mass of feed (g)	B: Rotational speed of ball mill (rpm)	C: Time of milling (min)	Average particle size (mm)
3	1	25	5	20	0.19
2	2	75	10	20	0.26
14	3	50	7.5	20	0.24
8	4	75	7.5	10	0.25
15	5	50	7.5	20	0.24
6	6	75	7.5	30	0.21
10	7	50	5	30	0.21
9	8	50	10	30	0.25
7	9	25	7.5	10	0.27
4	10	75	5	20	0.22
12	11	50	5	10	0.25
13	12	50	7.5	20	0.25
11	13	50	10	10	0.29
1	14	25	10	20	0.23
5	15	25	7.5	30	0.21

Table 3: *ANOVA for developed quadratic model for ball milling of C. sativum.*

Source	Sum of squares	df	Mean square	F value	p value	
Model	0.0089	9	0.0010	5.41	0.0388	Significant
A	0.0002	1	0.0002	1.09	0.3441	
B	0.0032	1	0.0032	17.45	0.0087	
C	0.0041	1	0.0041	22.09	0.0053	
AB	0.0000	1	0.0000	0.0000	1.0000	
AC	0.0001	1	0.0001	0.5455	0.4934	
BC	0.0000	1	0.0000	0.0000	1.0000	
A^2	0.0010	1	0.0010	5.59	0.0643	
B^2	0.0000	1	0.0000	0.0559	0.8224	
C^2	0.0003	1	0.0003	1.40	0.2901	
Residual	0.0009	5	0.0002			
Lack of fit	0.0008	3	0.0003	8.50	0.1071	Not-significant
Pure error	0.0001	2	0.0000			
Cor. total	0.0098	14				

Table 3 shows the ANOVA for developed quadratic model for ball milling of *C. sativum*. The developed model was significant with a F-value of 5.41 and a p-value of less than 0.05 with 95% confidence interval. Also, linear terms of rotational speed of ball mill and time of milling were significant with p-value of less than 0.05 and mass of feed is not significant with p-value of greater than 0.05. But, interactive terms involving mass of feed, rotational speed, and time of milling were insignificant with p-value, greater than 0.05. The same type of interactive pattern is followed for quadratic term also. This means that time of milling was found to be the significant factor followed by rotational speed and mass of feed, which is also confirmed from the ANOVA.

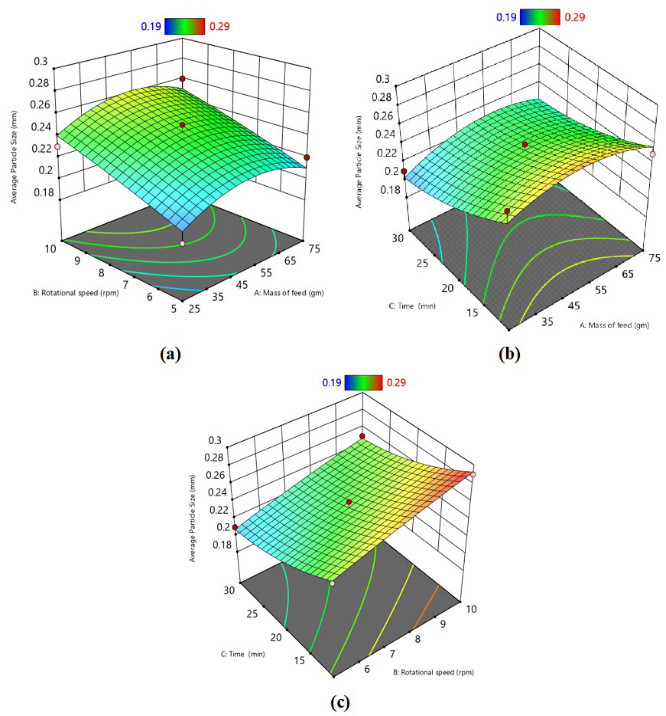

Figure 4: *3-D plots showing interactive effect between (a) mass of feed and rotational speed of milling, (b) mass of feed and time of milling, and (c) rotational speed and time of milling on average particle size of C. sativa seeds after ball milling.*

Figure 4a-c show the three-dimensional plots showing interactive effect between mass of feed and rotational speed of milling, mass of feed and time of milling, and rotational speed and time of milling on average particle size. At constant milling time of 20 min, the average particle size was 0.25, 0.22 and 0.21 mm at 25, 50 and 75 g of *Coriander sativum* seeds at 5 rpm of milling. The average particle size was 0.22, 0.24 and 0.23 mm at 25, 50 and 75 g of *Coriander sativum* seeds at 7.5 rpm of milling. The average particle size was 0.24, 0.26, and 0.25 mm at 25, 50 and 75 g of *C. sativum* seeds at 10 rpm of milling.

Links Researchers

At constant rotational speed of milling of 7.5 rpm, the average particle size was 0.26, 0.27 and 0.26 mm at 25, 50 and 75 g of *C. sativum* seeds at 10 min of milling. The average particle size was 0.22, 0.24 and 0.23 mm at 25, 50 and 75 g of *C. sativum* seeds at 20 min of milling. The average particle size was 0.2, 0.23, and 0.22 mm at 25, 50 and 75 g of *C. sativum* seeds at 30 min of milling. At constant mass of feed of 50 g, the average particle size was 0.25, 0.22 and 0.21 mm at 10, 20 and 30 min of *C. sativum* seeds at 5 rpm of milling. The average particle size was 0.27, 0.24 and 0.23 mm at 10, 20 and 30 min of *C. sativum* seeds at 7.5 rpm of milling. The average particle size was 0.29, 0.26 and 0.25 mm at 10, 20 and 30 min of *C. sativum* seeds at 10 rpm of milling (Özkaraaslan *et al.*, 2023; Banza and Rutto, 2022).

The determination coefficient (R^2) of 0.91 reveals the agreement of experimental values with predicted values of average particle size with *C. sativum* as feed material. A minimum average particle size of 0.18 mm at mass of feed, rolling speed and time of milling of 25 g, 5 rpm and 29 min, respectively (Nayak *et al.*, 2023; Shayo *et al.*, 2024), which means that minimum average particle size was achieved at lower level of mass of feed and rotational speed and higher milling time (Figure 4).

The developed models were further validated by repeating experiments under optimum conditions in triplicate and the response were found to be within 5% standard deviation. Hence, the average particle size from milling of *C. sativum* seeds has good potential for application in food industries.

Conclusions and Recommendations

Current research focuses on the use of round milling to extract nutrients and improve flavor of coriander seeds. The study investigated the effect of ball milling capacity (25, 50 and 75 g), milling duration (10 to 40 min), rotational speed (5 to 10 rpm) Various values of 29 minutes, 5 revolutions per minute, and 25 g were preferred to produce particles with an average diameter of 0.18 mm Analysis of Santi reaction surface method showed that the most important factor is milling time, followed by rotary speed and input mass so it can be said that the round mill method is the machine a very effective reduction *Coriander sativum* seeds.

Novelty Statement

This study highlights the potential to improve nutritional value and sensory attributes by optimizing ball milling parameters to produce fine, consistent particle sizes in food items. It illustrates how effective and adaptable the method is for a range of food industry applications.

Author's Contribution

Sivamani Selvaraju: Conceptualization, Writing - Review and Editing, Supervision, Project administration.
Naveen Prasad Balakrishna Pillai Sankari: Methodology, Data Curation, Writing - Original draft.
Halima Khalid Mohammed Al-Shukaili: Formal analysis, Investigation.
Mohammed Ahmed Al- Mashikhi: Formal analysis, Investigation.
Salim Said Salim Shaaban Bait Jamil: Formal analysis, Investigation.

Conflict of interest
The authors have declared no conflict of interest.

References

Aradwad, P.P., A.K. Tv, P.K. Sahoo and I. Mani. 2021. Key issues and challenges in spice grinding. Cleaner Eng. Technol., 5: 100347. https://doi.org/10.1016/j.clet.2021.100347

Baig, J.A., I.G. Chandio, T.G. Kazi, H.I. Afridi, K. Akhtar, M. Junaid and N.A. Malghani. 2023. Risk assessment of macronutrients and minerals by processed, street, and restaurant traditional Pakistani foods: A case study. Biol. Trace Element. Res., 201(7): 3553-3566. https://doi.org/10.1007/s12011-022-03429-7

Banerjee, S., S. Sivamani, R. Namdeti and B.N. Prasad. 2023. Optimization of biomethanation of water hyacinth (*Eichhornia crassipes*) using biocatalyst. Cellulose, 30(5): 2883-2894. https://doi.org/10.1007/s10570-023-05076-0

Banza, M. and R. Rutto. 2022. Extraction of cellulose nanocrystals from millet (*Eleusine coracana*) husk waste: Optimization using Box Behnken design in response surface methodology (RSM). Int. Nano Lett., 12(3): 257-272. https://doi.org/10.1007/s40089-022-

00369-x

Barnwal, P., P. Kumar, K.K. Singh, A. Mohite, S.N. Saxena and T.J. Zachariah. 2014. Grinding characteristics of coriander, fenugreek and black pepper under cryogenic and ambient grinding conditions. Int. J. Seed Spices, 4(1): 63-70.

Cao, Y., J. Zhao, Y. Tian, Z. Jin, X. Xu, X. Zhou and J. Wang. 2021. Physicochemical properties of rice bran after ball milling. J. Food Proc. Preserv., 45(10): e15785. https://doi.org/10.1111/jfpp.15785

Chemat, F., M.A. Vian, A.S. Fabiano-Tixier, M. Nutrizio, A.R. Jambrak, P.E. Munekata and G. Cravotto. 2020. A review of sustainable and intensified techniques for extraction of food and natural products. Green Chem., 22(8): 2325-2353. https://doi.org/10.1039/C9GC03878G

Gaikwad, P.S., N.B.P. Reddy, K. Sandhya and B.K. Yadav. 2023. Traditional vs. modern usage of nutri-cereals. In: Nutri-Cereals. CRC Press. pp. 27-56. https://doi.org/10.1201/9781003251279-2

Gao, W., F. Chen, X. Wang and Q. Meng. 2020. Recent advances in processing food powders by using superfine grinding techniques: A review. Comprehen. Rev. Food Sci. Food Saf., 19(4): 2222-2255. https://doi.org/10.1111/1541-4337.12580

Gharibzadeh, F., R.R. Kalantary, S. Nasseri, A. Esrafili and A. Azari. 2016. Reuse of polycyclic aromatic hydrocarbons (PAHs) contaminated soil washing effluent by bioaugmentation/biostimulation process. Separat. Purif. Technol., 168: 248-256. https://doi.org/10.1016/j.seppur.2016.05.022

Lamsal, B., H. Wang, P. Pinsirodom and A.T. Dossey. 2019. Applications of insect-derived protein ingredients in food and feed industry. J. Am. Oil Chem. Soc., 96(2): 105-123. https://doi.org/10.1002/aocs.12180

Li, H., S. van den Driesche, F. Bunge, B. Yang and M.J. Vellekoop. 2019. Optimization of on-chip bacterial culture conditions using the Box-Behnken design response surface methodology for faster drug susceptibility screening. Talanta, 194: 627-633. https://doi.org/10.1016/j.talanta.2018.10.048

Maroufi, K., H.A. Farahani and H.H. Darvishi. 2010. Importance of coriander (*Coriandrum sativum* L.) between the medicinal and aromatic plants. Adv. Environ. Biol., pp. 433-437.

Moghaddam, M.H., R. Nabizadeh, M.H. Dehghani, B. Akbarpour, A. Azari and M. Yousefi. 2019. Performance investigation of Zeolitic Imidazolate framework–8 (ZIF-8) in the removal of trichloroethylene from aqueous solutions. Microchem. J., 150: 104185. https://doi.org/10.1016/j.microc.2019.104185

Nam, S.N., H. Cho, J. Han, N. Her and J. Yoon. 2018. Photocatalytic degradation of acesulfame K: optimization using the Box–Behnken design (BBD). Process Saf. Environ. Prot., 113: 10-21. https://doi.org/10.1016/j.psep.2017.09.002

Nayak, C., B. Babu, V. Manoj, C.V. Raghunath, M. Bhatlu and P. Pandey. 2023. Optimization of process parameters by RSM-BBD for the removal of titan yellow dye from aqueous solution by acid-treated *Phyllanthus acidus* leaves. Biomass Conv. Biorefinery, pp. 1-17. https://doi.org/10.1007/s13399-023-04474-5

Özkaraaslan, H., S. Çetintaş and D. Bingöl. 2023. A novel composite derived from carbonized hawthorn waste pulp/marble waste powder by ball milling: preparation, characterization, and usability as bifunctional adsorbent. Biomass Conv. Biorefinery, 13(5): 3765-3784. https://doi.org/10.1007/s13399-021-01412-1

Saxena, S.N., P. Barnwal, S. Balasubramanian, D.N. Yadav, G. Lal and K.K. Singh. 2018. Cryogenic grinding for better aroma retention and improved quality of Indian spices and herbs: A review. J. Food Proc. Eng., 41(6): e12826. https://doi.org/10.1111/jfpe.12826

Selvaraju, S., B.P.S.N. Prasad and A. Cuento. 2023. Box-Wilson design and analysis for extraction of gelatin from black kingfish skin. Res. Innov. Food Sci. Technol.,

Sharifi, S., R. Nabizadeh, B. Akbarpour, A. Azari, H.R. Ghaffari, S. Nazmara and M. Yousefi. 2019. Modeling and optimizing parameters affecting hexavalent chromium adsorption from aqueous solutions using Ti-XAD7 nanocomposite: RSM-CCD approach, kinetic, and isotherm studies. J. Environ. Health Sci. Eng., 17: 873-888. https://doi.org/10.1007/s40201-019-00405-7

Shayo, G.M., E. Elimbinzi and G.N. Shao. 2024. Preparation methods, applications, toxicity and mechanisms of silver nanoparticles as bactericidal agent and superiority of green synthesis method. Heliyon. https://doi.org/10.1016/j.heliyon.2024.e36539

Shi, F. and W. Xie. 2015. A specific energy-based size reduction model for batch grinding ball mill. Miner. Eng., 70: 130-140. https://doi.org/10.1016/j.mineng.2014.09.006

Shin, H., S. Lee, H.S. Jung and J.B. Kim. 2013. Effect of ball size and powder loading on the milling efficiency of a laboratory-scale wet ball mill. Ceramics Int., 39(8): 8963-8968. https://doi.org/10.1016/j.ceramint.2013.04.093

Sivamani, S., B.N. Prasad, K. Nithya, N. Sivarajasekar and A. Hosseini-Bandegharaei. 2022. Back-propagation neural network: Box–Behnken design modelling for optimization of copper adsorption on orange zest biochar. Int. J. Environ. Sci. Technol., 19(5): 4321-4336. https://doi.org/10.1007/s13762-021-03411-1

Zhang, Z., G. Hao, G. Zhang, D. Hu, Q. Li, R. Cao and M. Hao. 2021. Optimization of formulation and operating parameters for ginkgo biloba extract nanosuspension by wet ball milling using a box–behnken design. J. Nanomater., 2021: 1-10. https://doi.org/10.1155/2021/6647593