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Optimization of continuous pre-milling treater for pre-milling treatment of chickpea

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Abstract
Chickpea (*Cicer arietinum* L.) is a vital leguminous crop rich in protein, fiber, and essential nutrients. Efficient pre-milling treatment is crucial for enhancing milling outcomes, ensuring product quality, and reducing energy consumption. This research paper focuses on the optimization of a continuous pre-milling treater tailored specifically for chickpea processing. The study involves the design, experimentation, and analysis of treater parameters to achieve optimal moisture content and texture for improved milling efficiency. The findings showcase the treater's effectiveness in enhancing chickpea processing and its potential contribution to the food processing industry. Optimization was done to obtain higher dehulling yield and dhal yield while minimizing the dehulling loss using response surface methodology. The best condition was obtained for chickpea with 14% moisture content treated with the microwave power level of 80% for about 2 min to achieve a dehulling yield of 45.21% and a dhal yield of 67.53%, dehulling loss of 6.96%.

Keywords: Chickpea, optimization, pre milling treatment, microwave

Introduction
Chickpea is a staple crop with significant nutritional value, making it essential for global food security. To maximize the yield and quality of chickpea-derived products, an efficient pre-milling treatment is necessary. Traditional pre-milling treatment methods often result in uneven conditioning and variable milling outcomes. The aim of this study is to optimize a continuous pre-milling treater designed to provide consistent and controlled conditioning for chickpea grains before the milling process. Chickpeas are the second most crucial crop globally, and India contributes about 65% of the total world production, being the largest chickpea producer globally. Previous research has explored various pre-milling treatment methods for chickpea, including soaking, dry heating, and steaming. However, these methods may not always ensure uniform moisture distribution, leading to suboptimal milling efficiency. Continuous processing solutions have shown promise in other grain processing industries, emphasizing the need for a tailored solution for chickpea. This paper builds upon existing research by proposing a continuous pre-milling treater optimized specifically for chickpea processing.

Materials and methods
Experimental materials
The continuous pre-milling treater is designed with a modular conveyor system that carries chickpea grains onto a vibrating bed. Steam injection and vibration ensure uniform moisture distribution across the grains. The treater's design allows for adjustable residence times, enabling customization based on chickpea variety and desired moisture content. The experimental methodology involves varying parameters such as steam flow rate, conveyor speed, and residence time to identify optimal conditions.

Samples
The chickpea (Desi) grains were procured from the local market of Ludhiana, Punjab, India. The grains were cleaned using cleaner cum grader and Destoner to separate all foreign matter, dust, dirt, twigs, broken and mud balls.

Determination of moisture content

The hot air oven method determined the sample's moisture content with drying at 102 ºC±2 for 24 h by the AOAC method. The average moisture content was found to be 10.04% (wb). Dehulling of chickpeas is performed at the optimum moisture content of 10% to 12% (Weight basis). Hence our sample was at the required moisture content, so we do not go for further dying of grain as we can achieve maximum dehulling at this moisture content.

A 3g weight of the samples was recorded on an analytical balance (Model: TB403, Dengver Instrument) of accuracy 0.001 g in triplicate, and their average value was recorded. The sample was kept into hot air oven for drying of moisture at optimum moisture range by putting in it for three different time intervals *viz.* 1 h, 2 h, and 3 h at 130 ºC and for each hour, samples were weighed, and calculated moisture content as per the below mentioned formula before conducting the designed experiments.

Moisture content (%) =$(W_1-W_2/W_1-W)*100$

Where,

W_1 = weight in g of the petri dish with the material before drying

W_2 = weight in g of the petri dish with the material after drying

W = weight in g of the empty petri dish.

Experimental run-on continuous microwave treatment

The continuous microwave treatment was performed in the developed system for continuous pre milling processing of chickpea. Pre-milling treatments of chickpea is labour and time-intensive batch operation, which is a big problem due to batch processing nature and results in excessive material handling, leading to increased processing duration with low final product recovery and chances of contamination in the handling process. For easy milling and to improve milling efficiency, pre-treatment of chickpea is required. So far, only long and batch type pre-milling treatments have been developed, and no such continuous type pre-milling treater is available for this purpose. Hence this study was undertaken to develop a continuous pre-milling treater for chickpea. A continuous pre-milling treater of 10 kg/h capacity was designed and developed. The developed system consisted of a treatment section, frame, microwave system, conveyor system, driving mechanism, and controlling unit. The developed system was optimized for continuous pre-milling treatments of chickpea to determine the best treatment condition for maximizing dehulling yield and dhal yield while minimizing the dehulling loss. The triplicate of each sample was taken in order to avoid an error. The samples were packed in plastic bags with proper coding of power level and time.

Dehulling parameters of chickpea

Dehulling parameters were determined in terms of dehulling yield, dhal yield, and dehulling loss.

- Dehulling yield (DeY) was defined as total whole dehulled kernels and broken kernels produced in the dehulling of pulses. The dehulling yield was calculated using the relation given by (Goyal *et al*. 2007) [5].

$$\text{De Y (\%)} = \frac{\textit{weight of dehulled kernel}(g) + \textit{weight of broken}(g)}{\textit{Initial weight of pigeonpea}} \times 100$$

- Dhal yield (DY) was defined as the yield of dehulled whole and split kernels as a percentage of initial seed weight (APQ Method 104.1, Burridge *et al*. 2001) [16]. Dhal yield was calculated using the relation given by (Goyal *et al*. 2007) [5].

$$\text{DY (\%)} = \frac{\textit{mass of dehulled whole+split seed}(g)}{\textit{Initial weight of pigeon pea}} \times 100$$

- Dehulling loss (DL) was calculated as the weight fraction of the powder and fine broken relative to the initial weight of chickpea. It was calculated using the relation given by (Goyal *et al*. 2007) [5].

$$\text{DL (\%)} = \frac{\textit{weight of powder}(g) + \textit{wt of fine broken}(g) + \textit{machine loss}}{\textit{Initial weight of pigeon pea}} \times 100$$

Statistical Evaluation

All measurements were carried out in triplicate, and the results were expressed as the mean. To fit regression equations, M.S. Excel was utilized.

Results and discussions

Through a series of controlled experiments, the optimization of treater parameters for chickpea pre-milling treatment is achieved. Varying steam flow rates and residence times reveal significant impacts on moisture absorption and texture. Higher steam flow rates result in quicker moisture absorption, while longer residence times lead to more uniform conditioning. The optimal combination of parameters is determined to maximize chickpea milling efficiency and produce consistent end products.

Performance evaluation of continuous pre-milling treater

Chickpea was pre-treated in the developed continuous pre-milling treater at different combinations of moisture content, microwave power level, and treatment time as listed in experimental design in table 1. The treated grain samples were analysed for their response to dependent variables, i.e., dehulling parameters *viz*., dehulling yield, dhal yield, dehulling loss, and average surface temperature by varying the independent variables *viz*., moisture content of the grains, microwave power level, and treatment time were determined with the combination of various parameters used in design expert software. The quadratic model was fitted to the experimental data to check the adequacy of the model. The multiple regression techniques developed the response surface analysis of different response parameters as a function of process variables. Various three-dimensional response surfaces were developed to view a variance in processing variable responses and were drawn using Design Expert Software (design expert - 8.0.2).

Table 1: Combinations of various parameters used in design expert software for chickpea

Sl	Run	Moisture content % (w.b.)	Power level %	Treatment Time	Dehulling yield %	Dhal yield %	Dehulling loss %	Temperature (°C)
11	1	12	100	1.0	40.84	66.87	9.49	59.1
1	2	10	100	1.5	57.86	70.30	11.48	70.6
2	3	14	100	1.5	39.53	66.84	7.82	80.2
9	4	12	100	2.0	43.95	66.15	8.34	87.4
15	5	12	80	1.5	35.78	58.74	7.87	49.1
10	6	12	60	2.0	36.91	61.03	7.56	47.3
5	7	10	80	2.0	54.51	63.68	8.57	58.8
4	8	14	60	1.5	28.13	53.71	5.06	47.8
3	9	10	60	1.5	30.77	58.02	6.06	47.7
12	10	12	60	1.0	33.82	56.49	7.26	44.9
16	11	12	80	1.5	39.87	60.09	8.42	53.0
8	12	14	80	1.0	30.02	56.78	6.06	45.9
7	13	10	80	1.0	51.66	59.03	8.35	43.7
13	14	12	80	1.5	35.11	55.17	6.47	50.5
17	15	12	80	1.5	39.71	58.77	6.85	67.2
14	16	12	80	1.5	39.34	56.85	6.68	72.4
6	17	14	80	2.0	44.49	67.06	6.92	82.8

Effects of continuous microwave treatments on dehulling parameters of chickpea

Dehulling yield

The dehulling yield of chickpea was obtained between 28.13% and 57.86% during different treatment combinations. The minimum dehulling yield (28.13%) was obtained at 14% moisture content, 60% power level, and 1.5 min treatment time in the developed continuous pre-milling treater which was found to be about 2.06 times less than the maximum dehulling yield (57.86%) obtained at 10% moisture content, 100% power level and 1.5 min treatment time (Table 2). The coefficient of the model and other statistics is specified in Table 2.

It was observed from Fig. 1 that the dehulling yield increased as increasing from 38.79% to 59.55%, the power level for the entire range from 60% to 100% power level. High microwave treatment disrupts the link between the hull and cotyledon, which increases dehulling effectiveness (Sokhansanj and Patil, 2003; Ramakrishnaiah and Kurien, 1983) [13, 14]. A similar trend was observed by Joyner and Yadav (2015) [15] for treating black gram in continuous hydrothermal treater. The dehulling yield initially decreased with increasing moisture content from 38.79% to 35.27% and then increased again to 39.13% with increasing moisture content due to its conductance for microwave treatment. The minimum dehulling yield was observed at a 60% power level instead of 100%. Although moisture is not significantly affecting the yield, power level and treatment time were significantly affected, and it was less affected during continuous pre-milling treatment for chickpea in the developed system. It is standard worldwide that the dehulling yield decreases with increasing moisture content. Ramakrishnaiah and Kurien (1983) [14] also detected the same effect for milling yield increased with increased microwave power level or exposure time for its better effect of microwave dosage due to its higher moisture content and easily denatured the gum layer between seed coat and cotyledon. Fig. 1 demonstrates the cumulative effect of moisture content and microwave power level on dehulling yield of chickpea.

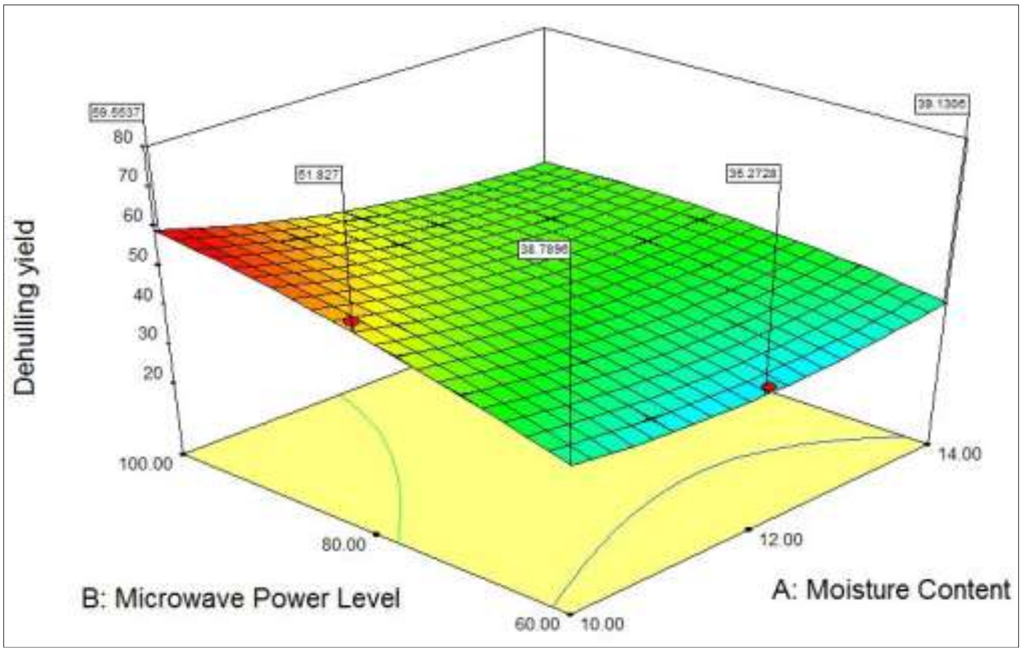

Fig 1: Cumulative effect of moisture content and microwave power level on dehulling yield of chickpea

It was observed from Fig. 2 that the dehulling yield increased as increasing from 38.60% to 59.49%, the power level for the entire range from 60% to 100% power level. A similar trend was observed by Joyner and Yadav (2015) [15] for treating black gram in continuous hydrothermal treater. The dehulling yield decreased as treatment time increased from 1 min to 1.5 min, initially from 38.60% to 35.26%, then increased again up to 38.64% with increasing treatment time up to 2 min due to more microwave treatments in the machine for its continuous microwave pre-milling treatment. The minimum dehulling yield was observed at a 60% power level instead of 100%. Fig. 2 demonstrates the cumulative effect of microwave power level and treatment time on the dehulling yield of chickpea.

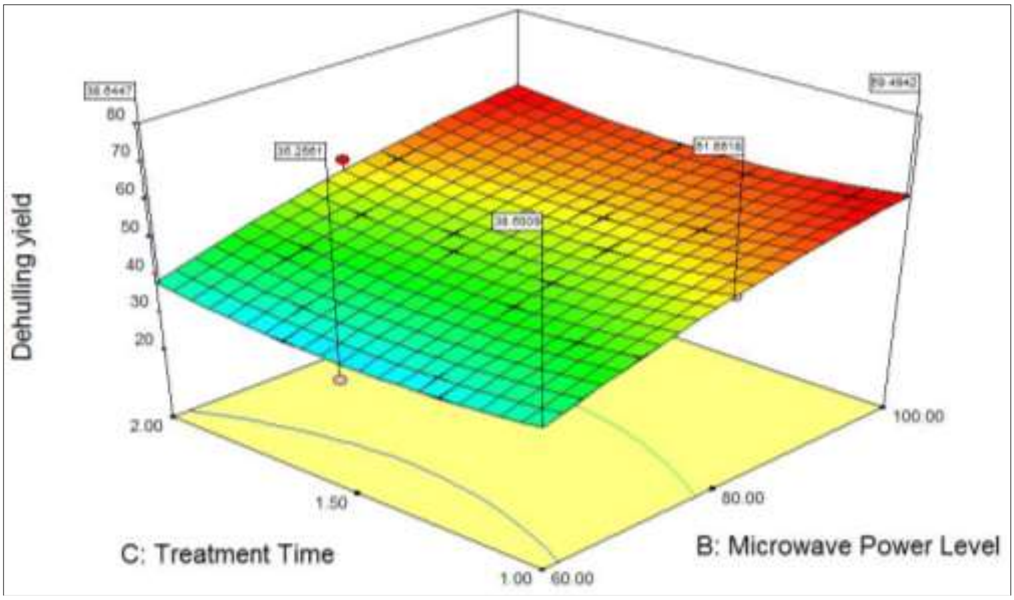

Fig 2: Cumulative effect of microwave power level and treatment time on dehulling yield of chickpea

Dehulling yield = $35.60 - 4.32A + 4.61B + 4.39C - 5.88AB + 4.46AC + 5\times10^{-3}BC + 8.33A^2 - 2.59B^2 + 3.51C^2$ ….. (1)

Where,
A = Moisture content (% w.b.)
B = Microwave power level (%)
C = Treatment time (min)

ANOVA was directed to determine the significance of moisture content, microwave power level, and treatment time on dehulling yield and shown in Table 2. The ANOVA shows a computed F value (6.13) which is greater than the tabulated F value (1.30), recommending that the model is effectively utilized to fit the investigational information at a 5% level of significance ($p<0.05$). Analysis of variance of Eq. 1 displays that F values for linear terms of microwave power level and treatment time are 6.30 and 5.72 with P values of less than 0.05, showing that the B ($p<0.05$) and C ($p<0.05$) are extremely significant terms.

Table 2: Analysis of variance for dehulling yield of chickpea

Source	Sum of Squares	df	Mean Square	F Value	P-Value Prob > F
Model	991.71	9	110.19	6.13	0.0130^{s}
Linear terms					
A-Moisture content	22.86	1	22.86	1.27	0.2966
B-Microwave power level	113.22	1	113.22	6.30	0.0404^{s}
C-Treatment time	102.90	1	102.90	5.72	0.0480^{s}
Interaction terms					
AB	61.54	1	61.54	3.42	0.1067
AC	33.76	1	33.76	1.88	0.2129
BC	0.0001	1	0.0001	5.56×10^{-6}	0.9982
Quadratic terms					
A^2	57.65	1	57.65	3.21	0.1164
B^2	28.24	1	28.24	1.57	0.2503
C^2	51.81	1	51.81	2.88	0.1334
Residual	125.83	7	17.98		
Lack of Fit	104.34	3	34.78	6.47	0.0515^{ns}
Pure Error	21.49	4	5.37		
Cor Total	1117.54	16			

Dhal yield

The dhal yield of chickpea was obtained between 53.71% and 70.30% during different treatment combinations. The minimum dhal yield (53.71%) was obtained at 14% moisture content, 60% power level, and 1.5 min treatment time in the developed continuous pre-milling treater which was found to be about 1.31 times less than the maximum dehulling yield (70.30%) obtained at 10% moisture content, 100% power level and 1.5 min treatment time (Table 3). The coefficient of the model and other statistics is specified in Table 3.

It was observed from Fig. 3 that the dhal yield increased as increasing from 62.39% to 69.56%, the power level for the entire range from 60% to 100% power level. At a higher power level, microwave pre-milling treatment could denature the gum protein between the husk and cotyledon, breaking the link between the two. A similar trend was observed by (Sokhansanj and Patil, 2003) [13], and these findings were correlated with this study. The dhal yield decreased with increasing moisture content, initially from 62.39% to 61.17%, then increasing again to 63.14% due to its conductance for microwave treatment. The minimum dhal yield was observed at a 60% power level instead of 100%. As per the model, the moisture content is not affected significantly and had little effect on dhal yield during continuous pre-milling treatment of chickpea and combined effect showing the meagre decreasing findings. Fig. 3 demonstrates the cumulative effect of moisture content and microwave power level on the dhal yield of chickpea.

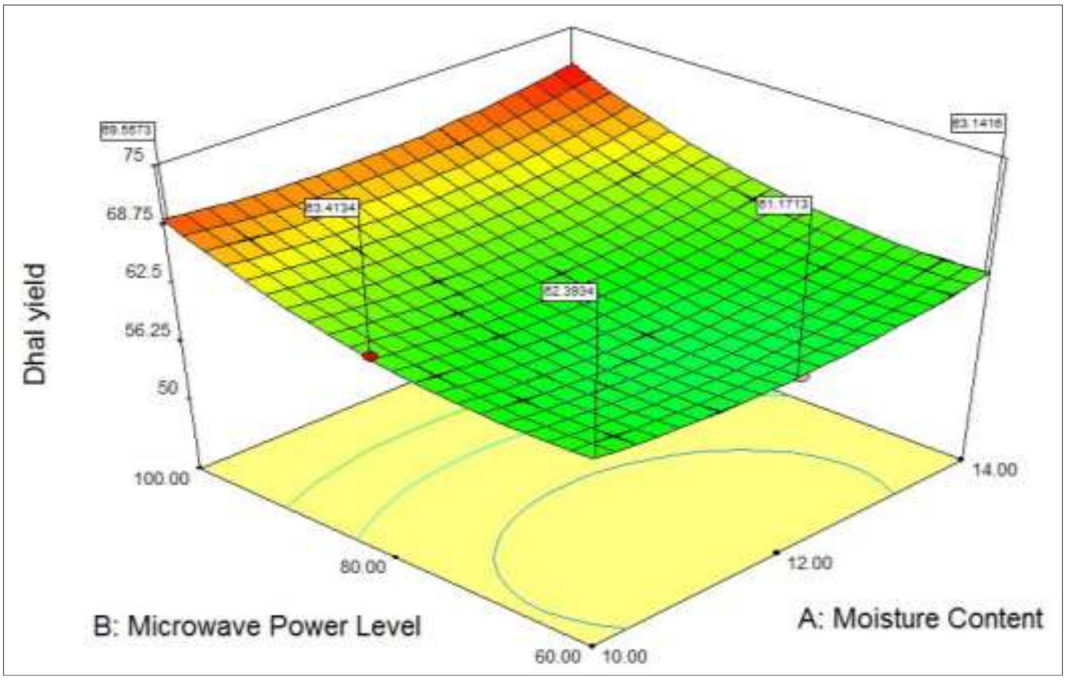

Fig 3: Cumulative effect of moisture content and microwave power level on dhal yield of chickpea

It was observed from Fig. 4 that the dhal yield increased as increasing from 53.06% to 66.05%, the power level for the entire range from 60% to 100% power level. At more extended treatment periods, microwave pre-milling could denature the gum protein between the husk and cotyledon, rendering the link between the husk and cotyledon untenable. A similar trend was observed by (Sokhansanj and Patil, 2003) [13], and these findings were correlated with this study. The dhal yield increased as increasing treatment time from 1 min to 2 min from 53.06% to 61.74% due to more microwave treatments in the machine for its continuous microwave pre-milling treatment. The minimum dehulling yield was observed at a 60% power level instead of 100%. It was due to the treated grains being highly exposed to higher microwave treatments during the continuous pre-milling treatment process in the developed system gives better results due to its loosening of the gum layer between coat and cotyledon. Fig. 4 demonstrates the cumulative effect of microwave power level and treatment time on the dhal yield of chickpea.

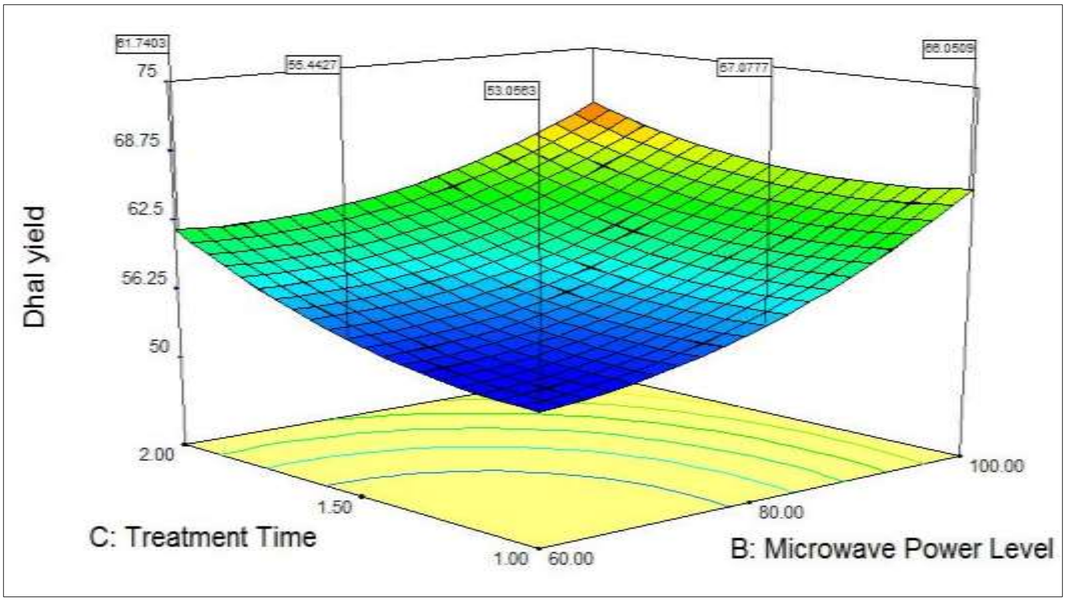

Fig 4: Cumulative effect of microwave power level and treatment time on dhal yield of chickpea

Dhal yield = $57.92 + 1.23A + 5.22B + 3.05C + 0.32AB + 2.11AC – 1.31BC + 3.71A^2 + 2.65B^2 + 2.07C^2$ ….. (2)

Where,
A = Moisture content (% w.b.)
B = Microwave power level (%)
C = Treatment time (min)

ANOVA was directed to determine the significance of moisture content, microwave power level, and treatment time on dhal yield, as shown in Table 3. The ANOVA shows a computed F value (5.03) which is greater than the tabulated F value (2.23), recommending that the model is effectively utilized to fit the investigational information at a 5% level of significance ($p<0.05$). Analysis of variance of Eq. 2 displays that F values for linear terms of microwave power level and treatment time are 19.41 and 6.61, and quadratic terms of microwave power level are 3.94 with P values of less than 0.05, showing that the B ($p<0.05$), C ($p<0.05$), and B^2 are extremely significant terms.

Table 3: Analysis of variance for dhal yield of chickpea

Source	Sum of Squares	df	Mean Square	F Value	P-Value Prob > F
Model	339.12	9	37.68	5.03	0.0223^s
Linear terms					
A-Moisture content	1.85	1	1.85	0.25	0.6348
B-Microwave power level	145.32	1	145.32	19.41	0.0031^s
C-Treatment time	49.53	1	49.53	6.61	0.0369^s
Interaction terms					
AB	0.18	1	0.18	0.024	0.8810
AC	7.92	1	7.92	1.06	0.3378
BC	6.92	1	6.92	0.92	0.3685
Quadratic terms					
A^2	11.44	1	11.44	1.53	0.2564
B^2	29.47	1	29.47	3.94	0.0877
C^2	17.96	1	17.96	2.40	0.1654
Residual	52.42	7	7.49		
Lack of Fit	37.61	3	12.54	3.39	0.1348^{ns}
Pure Error	14.81	4	3.70		
Cor Total	391.54	16			

Dehulling loss

The dehulling loss of chickpea was obtained between 5.06% and 11.48% during different treatment combinations. The minimum dhal yield (5.06%) was obtained at 14% moisture content, 60% power level, and 1.5 min treatment time in the developed continuous pre-milling treater which was found to be about 2.27 times less than the maximum dehulling loss (11.48%) obtained at 10% moisture content, 100% power level and 1.5 min treatment time (Table 4). The coefficient of the model and other statistics is specified in Table 4.

It was observed from Fig. 5 that the dehulling loss increased as increasing from 6.78% to 11.57%, the power level for the entire range from 60% to 100% power level. Higher microwave dosage resulted in higher losses and decreased the whole kernels due to the crystallinity and brittleness effect higher microwave dosage during pre-milling treatments. Similar outcomes were initiated by Deshpande *et al*. (2007). The dehulling loss decreased as increasing moisture content from 6.78% to 5.64% in the entire range due to its conductance for microwave treatment. The minimum dehulling loss was detected at a 60% power level instead of 100%. The structural damage caused by denatured proteins increases broken and tiny particles at these high temperatures. Additionally, Ramakrishnaiah and Kurien (1983) [14] reported that increased temperature initially enhanced dehulling loss. Fig. 5 demonstrates the cumulative effect of moisture content and microwave power level on the dehulling loss of chickpea.

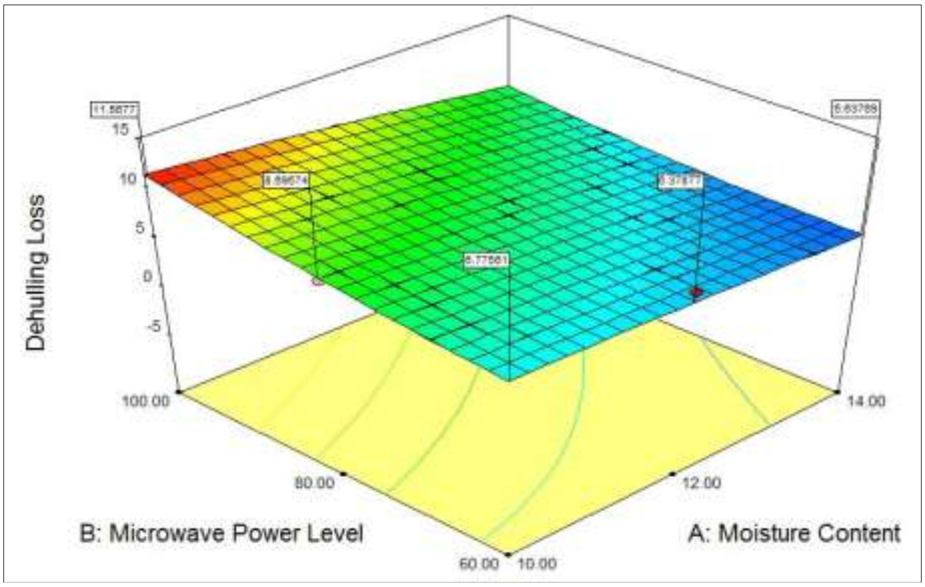

Fig 5: Cumulative effect of moisture content and microwave power level on dehulling loss of chickpea

It was observed from Fig. 6 that the dehulling loss increased, increasing from 6.80% to 11.62 the power level for the entire range from 60% to 100% power level. High-powered microwaves destroy the link between the shell and cotyledon (Sokhansanj and Patil, 2003) [13]; it increases dehulling effectiveness (Ramakrishnaiah and Kurien, 1983) [14]. A similar trend was observed by Joyner and Yadav (2015) [15] for treating black gram in continuous hydrothermal treater. The dehulling loss decreased slightly as treatment time increased from 1 min to 1.5 min from 6.80% to 6.62% and increased up to 2 min due to the severity of longer treatments. The minimum dehulling yield was observed at a 60% power level instead of 100%. It was due to the treated grains giving good dehulling yields and less dehulling loss during higher exposure to microwave treatments during the continuous pre-milling treatment process in the developed system. Fig. 6 demonstrates the cumulative effect of microwave power level and treatment time on the dehulling loss of chickpea.

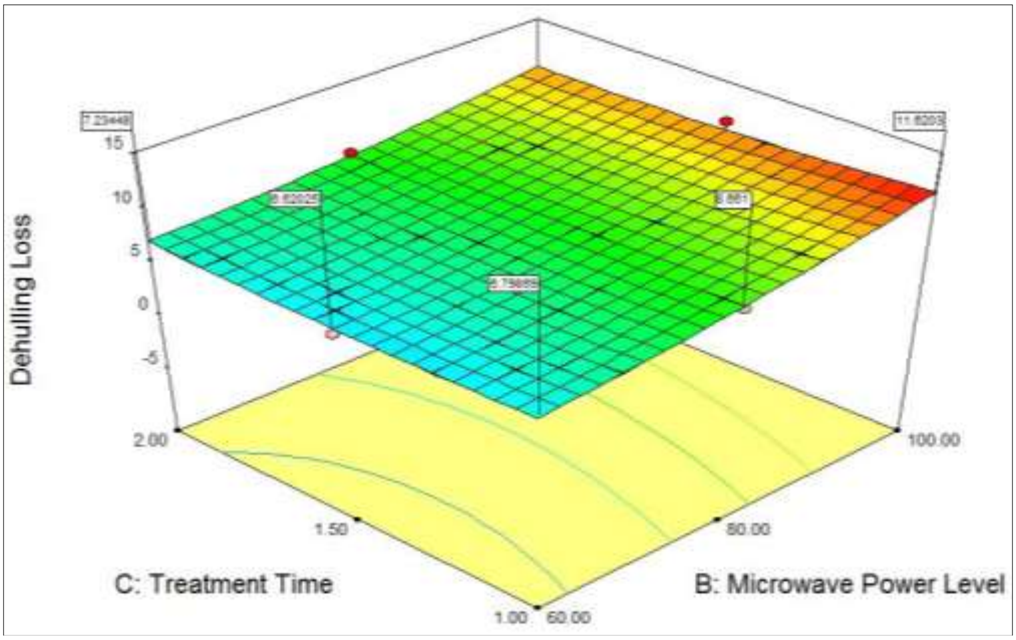

Fig 6: Cumulative effect of microwave power level and treatment time on dehulling loss of chickpea

$$\text{Dehulling loss} = 6.68 - 1.87A + 1.07B + 0.11C - 1.00AB + 0.24AC - 0.36BC - 0.38A^2 + 0.52B^2 + 0.39C^2 \quad \ldots\ (3)$$

Where,
A = Moisture content (% w.b.)
B = Microwave power level (%)
C = Treatment time (min)

ANOVA was directed to determine the significance of moisture content, microwave power level, and treatment time on dehulling loss and shown in Table 4. The ANOVA shows a computed F value (3.38) which is less than the tabulated F value (6.11), recommending that the model is not effectively utilized to fit the investigational information at a 5% level of significance ($p<0.05$). Analysis of variance of Eq. 3 displays that F values for linear terms of microwave power level are 6.32 with P values of less than 0.05, showing that the B ($p<0.05$) is extremely significant.

Table 4: Analysis of variance for dehulling loss of chickpea

Source	Sum of Squares	df	Mean Square	F Value	P-Value Prob > F
Model	29.21	9	3.25	3.38	0.0611^{ns}
Linear terms					
A-Moisture content	4.28	1	4.28	4.46	0.0727
B-Microwave power level	6.06	1	6.06	6.32	0.0402^{s}
C-Treatment time	0.063	1	0.063	0.066	0.8050
Interaction terms					
AB	1.77	1	1.77	1.84	0.2167
AC	0.10	1	0.10	0.11	0.7535
BC	0.53	1	0.53	0.55	0.4833
Quadratic terms					
A^2	0.12	1	0.12	0.13	0.7319
B^2	1.13	1	1.13	1.17	0.3145
C^2	0.63	1	0.63	0.66	0.4440
Residual	6.72	7	0.96		
Lack of Fit	3.87	3	1.29	1.81	0.2844^{ns}
Pure Error	2.85	4	0.71		
Cor Total	35.93	16			

Temperature

The temperature of chickpea was obtained between 43.7 ºC and 87.4 ºC during different treatment combinations. The minimum temperature (43.7 ºC) was obtained at 10% moisture content, 60% power level, and 1 min treatment time in the developed continuous pre-milling treater which was found to be about 2 times less than the maximum temperature (87.4 ºC) obtained at 10% moisture content, 100% power level, and 1.5 min treatment time (Table 5). The coefficient of the model and other statistics is specified in Table 5.

It was observed from Fig. 7 that the temperature increased from 43.7 ºC to 78.8 ºC and the power level for the entire range from 60% to 100% power level. It happened due to increased treatment of microwave radiation exposure to higher microwave treatments with increased microwave energy (microwave power-on time) and increased microwave power level. A similar trend was observed by Joyner and Yadav (2015) [15] for treating black gram in continuous hydrothermal treater. The temperature increased as moisture content increased from 43.7 ºC to 58.0 ºC in the entire range due to its higher residence time for continuous microwave pre-milling treatments in the treatment chamber. The minimum temperature was observed at a 60% power level instead of 100%. It was due to the higher exposure to microwave radiation during the continuous pre-milling treatment process in the developed system. Fig. 7 demonstrates the cumulative effect of moisture content and microwave power level on the temperature of chickpea.

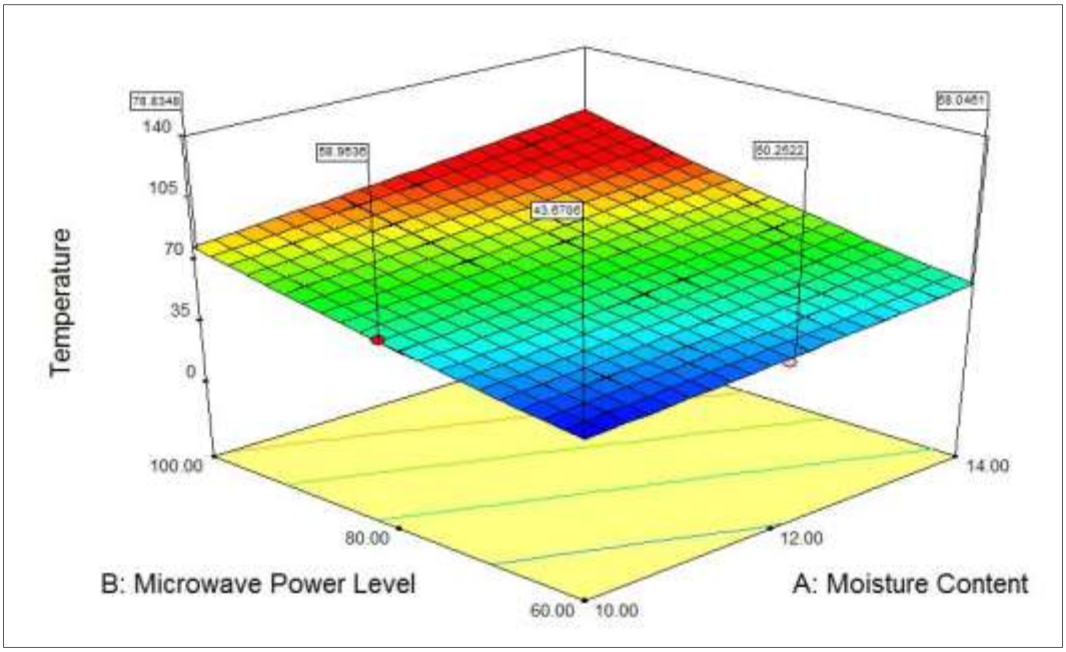

Fig 7: Cumulative effect of moisture content and microwave power level on temperature of chickpea

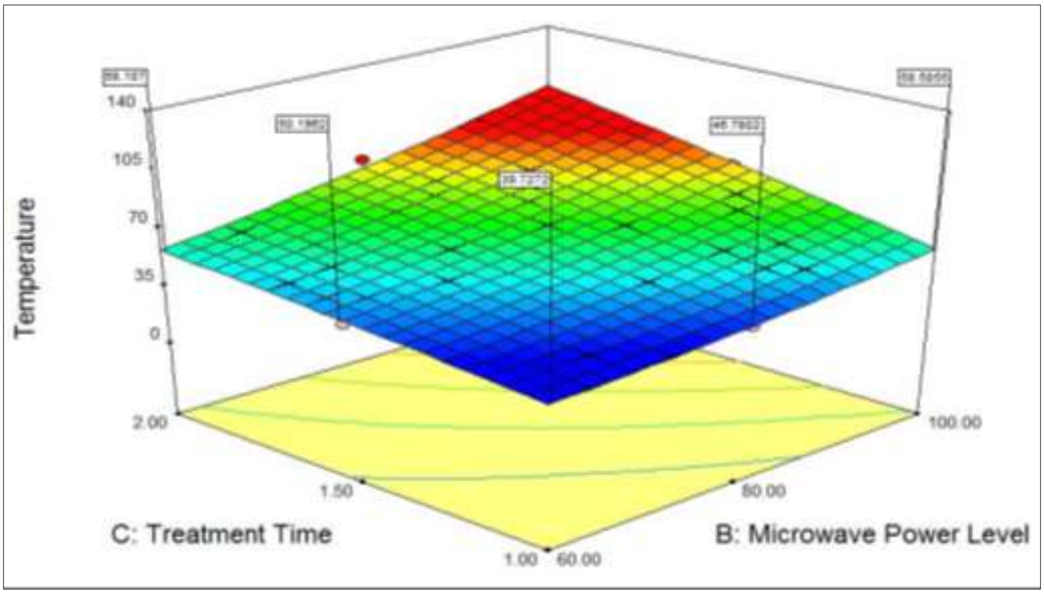

Fig 8: Cumulative effect of microwave power level and treatment time on temperature of chickpea

It was observed from Fig. 8 that the temperature increased as increasing from 39.7 ºC to 58.6 ºC, and the power level for the entire range was from 60% to 100% power level. It happened due to the increased effect of microwave dosage on the treated grains. A similar trend was observed by Joyner and Yadav (2015) [15] for treating black gram in continuous hydrothermal treater. The temperature increased as increasing treatment time from 1 min to 2 min from 39.7 ºC to 58.1 ºC due to the severity of longer treatments. The minimum temperature was observed at a 60% power level instead of

100%. It was due to the treated grains going for more prolonged treatment time during continuous pre-milling treatment in the developed system giving higher radiations. Fig. 8 demonstrates the cumulative effect of microwave power level and treatment time on the temperature of chickpea.

$$Temperature = 60.81 + 7.68A + 14.89B + 13.06C + 3.56AB + 7.80AC + 6.48BC + 1.70A^2 + 2.38B^2 - 1.14C^2 \quad \ldots (4)$$

Where,
A = Moisture content (% w.b.)
B = Microwave power level (%)
C = Treatment time (min)

ANOVA was directed to determine the significance of moisture content, microwave power level, and treatment time on dehulling loss and shown in Table 5. The ANOVA shows a computed F value (4.09) which is greater than the tabulated F value (3.84), recommending that the model is effectively utilized to fit the investigational data at a 5% level of significance ($p<0.05$). Analysis of variance of Eq. 4 displays that F values for linear terms of microwave power level and treatment time are 15.22 and 11.71 with P values of less than 0.05, showing that the A ($p<0.05$) and B ($p<0.05$) are extremely significant terms.

Table 5: Analysis of variance for temperature of chickpea

Source	Sum of Squares	df	Mean Square	F Value	P-Value Prob > F
Model	2859.02	9	317.67	4.09	0.0384^{s}
Linear terms					
A-Moisture content	72.24	1	72.24	0.93	0.3670
B-Microwave power level	1182.07	1	1182.07	15.22	0.0059^{s}
C-Treatment time	910.02	1	910.02	11.71	0.0111^{s}
Interaction terms					
AB	22.56	1	22.56	0.29	0.6067
AC	108.16	1	108.16	1.39	0.2766
BC	167.70	1	167.70	2.16	0.1852
Quadratic terms					
A^2	2.40	1	2.40	0.031	0.8655
B^2	23.85	1	23.85	0.31	0.5968
C^2	5.52	1	5.52	0.071	0.7975
Residual	543.81	7	77.69		
Lack of Fit	92.32	3	30.77	0.27	0.8429^{ns}
Pure Error	451.49	4	112.87		
Cor Total	3402.83	16			

Conclusion

The optimized continuous pre-milling treater offers several benefits for chickpea processing. By achieving uniform conditioning, the treater enhances milling efficiency, reduces energy consumption, and increases product yield. The resulting chickpea flours exhibit improved texture, color, and nutritional content, making them suitable for various food applications. Additionally, the treater's continuous operation minimizes processing time and labor requirements. The optimization of the continuous pre-milling treater for chickpea processing represents a significant advancement in pulse processing technology. The study demonstrates the treater's capability to achieve consistent and controlled pre-milling conditioning, ultimately improving milling efficiency and product quality. This research contributes to the growing body of knowledge on continuous processing solutions for food industries, highlighting their potential for sustainable and efficient food production. Further research avenues can build upon this study by investigating the treater's scalability for larger processing facilities and exploring its adaptability to different chickpea varieties. Additionally, the integration of advanced sensor technologies and real-time monitoring systems could enhance the treater's performance and accuracy in achieving optimal conditions. Long-term studies on the treater's economic viability and its potential to reduce post-processing waste could also be pursued. In conclusion, the optimization of the continuous pre-milling treater for chickpea processing holds promise in enhancing milling outcomes and product quality. By offering a controlled and uniform pre-milling treatment, the treater contributes to efficient chickpea processing and elevates the overall value of chickpea-derived products. As food industries seek sustainable and innovative solutions, the treater's potential to revolutionize chickpea processing underscores its significance in shaping the future of food production and nutrition. The best condition was obtained for chickpea with 14% moisture content treated with the microwave power level of 80% for about 2 min to achieve a dehulling yield of 45.21% and a dhal yield of 67.53%, dehulling loss of 6.96%.

References

1. Anon. Agricultural statistics at a glance (2004). Directorate of economics and statistics. Ministry of Agriculture Government of India. New Delhi; c2004.
2. Chacko J, Saxena RP, Kumbhar BK, Agrawal US. Chickpea milling: A status report. National seminar on emerging trends in processing, handling, storage, and by-product utilization of pulses and soybean. GBPUAT, Pantnagar; c2001.
3. Chavan JK, Kadam SS, Salunkhe DK, Beuchat LR. Biochemistry and technology of chickpea (*Cicer arietinum* L.) seeds. Critical Reviews in Food Science & Nutrition. 1987 Jan 1;25(2):107-58.
4. Dronachari M, Yadav BK. Application of Microwave Heat Treatment in Processing of Pulses. Journal of Academia and Industrial Research (JAIR); c2015. Youth Education and Research Trust (YERT) jairjp.com, ISSN: 2278-5213 401.
5. Goyal RK, Vishwakarma RK, Wanjari OD. Optimization of the chickpea dehulling process. PH—Postharvest Technology. 2007;9(25):1941-1947.
6. Goyal RK, Vishwakarma RK, Omkar. Optimization of process parameters and mathematical modeling for dehulling of chickpea. Food Science Technology. 2008;44(1):36-41.

7. Kurien P. Postharvest technology of chickpea. In: Saxena MC, Singh KB, eds. The chickpea; CAB International; c1987.
8. Mangaraj S, Singh KP. Optimization of machine parameters for milling of chickpea using RSM. Food Bioprocess and Technology; c2009. doi:10.1007/s 11947-008-021-x.
9. Miao M, Zhang T, Jiang B. Characterisations of kabuli and desi chickpea starches cultivated in China. Food chemistry. 2009 Apr 15;113(4):1025-32.
10. Singh KB. Chickpea (*Cicer arietinum* L.). Field crops research. 1997 Jul 1;53(1-3):161-70.
11. Srivastava S. Comparison of various pre-milling treatments of chickpea (*Cajuns cajan* L.) grain on a laboratory mill, M.Tech (Agricultural Engineering) Thesis, G.B. Pant University of Agricultural and Technology, Pantnagar; c1999.
12. Tiwari BK, JaganMohan R, Venkatachalapathy N, Anand MT, Surabi A, Alagusundaram K, *et al*. Optimisation of hydrothermal treatment for dehulling pigeon pea. Food research international. 2010 Mar 1;43(2):496-500.
13. Sokhansanj SH, Patil RT. Dehulling and splitting pulses. Handbook of postharvest technology: cereals, fruits, vegetables, tea, and spices. 2003;93:397.
14. Ramakrishnaiah N, Kurien PP. Variabilities in the dehulling characteristics of pigeon pea (*Cajanus cajan* L.) cultivars. Journal of Food Science and Technology. 1983;20(6):287-91.
15. Joyner JJ, Yadav BK. Microwave assisted dehulling of black gram (*Vigna mungo* L). Journal of Food Science and Technology. 2015 Apr;52(4):2003-12.
16. Burridge JH, Wood DE, Taylor PN, McLellan DL. Indices to describe different muscle activation patterns, identified during treadmill walking, in people with spastic drop-foot. Medical engineering & physics. 2001 Jul 1;23(6):427-34.