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Optimization of continuous pre-milling Treater for pre-milling treatment of Pigeonpea

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Abstract
Pre-milling treatments of pigeon pea are 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 pigeon pea 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 the developed system of 10 kg/h capacity of continuous pre milling treater for pigeon pea was optimized for continuous treatments of pigeon pea to determine the best treatment condition for maximizing dehulling yield and dhal yield while minimizing the dehulling loss. The best condition was obtained for pigeon pea with 10% moisture content treated with the microwave power level of 90% for about 1.5 min to achieve a dehulling yield of 49.15%, dhal yield of 74.55%, dehulling loss of 7.67%. Thus, it is recommended that the continuous pre-milling treatment is more suitable for pigeon pea processing and presents an improvised short and continuous method for pre-milling treatments for commercial adoption.

Keywords: Pigeon pea, optimization, pre milling treatment, microwave

Introduction

Although dehulling itself is a continuous process but its pre-milling treatments are lengthy and time consuming. Basically, pre milling treatments are being done for enhancing the dhal recovery but sill these all processes very time consuming. Hence, there is no such complete and short pre-milling treatment is available so that process time may be reduced with improved milling quality and dhal recovery in single pass in continuous mode for efficient milling of pulses. However, besides being labour intensive, time consuming, shape deformation and poor cooking quality the dehulling efficiency is not that much improved by these pre-treatments. Moreover, the varietal differences in pigeon pea also demands for variety specific pre-milling treatments. Pitting or surface scratching is one of the basic unit operations performed prior to application of any pre-milling treatments in the pulse milling (Singh, 1995; Narasimha *et al*., 2003) [19, 23]. This operation improves absorption of the pre-treatment agents (Narasimha *et al*., 2003; Rodino *et al*., 2011) [23]. Hence, in this study pre-milling treatments will be studied. Dehulling of pulses for dhal production with abrasive machines is performed when the grain attains moisture content of around 10% and it is irrespective of the pre-treatment method employed. Dehulling of the pulses is usually done with the application of abrasive forces (Sokhansanj and Patil, 2003) [20]. Consequently, several machines have been developed for dehulling of pulses. Most common commercial machine for pulse dehulling is the emery-coated cylinder-concave system (Singh, 1995) [19]. Pulse dehulling machines developed by different research organizations of India are the modified versions of the batch type dehulling machines used in the commercial pulse milling industries. It may be observed that all the dehulling machines are based on the principle of abrasion and these dehull 80–88% pigeon pea seeds using different pre-treatments in 3–4 passes.

Materials and Methods

Experimental Materials

The continuous pre-milling treater is designed with a modular conveyor system that carries pigeon pea 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 pigeon pea 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 pigeon pea 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 (AOAC, 1990; Singh and Sahay, 1994) [24]. The average moisture content was found to be 10.04% (wb). Dehulling of pigeon peas 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 pigeon pea. Pre-milling treatments of pigeon pea 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 pigeon pea 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 pigeon pea. 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 pigeon pea 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 pigeon pea

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) [6].

$$\text{DeY (\%)} = \frac{\text{weight of dehulled kernel(g)+weight of broken (g)}}{\text{Initial weight of pigeon pea}} \times 100$$

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). Dhal yield was calculated using the relation given by (Goyal *et al*. 2007) [6].

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

Dehulling loss (DL) was calculated as the weight fraction of the powder and fine broken relative to the initial weight of pigeon pea. It was calculated using the relation given by (Goyal *et al*. 2007) [6].

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

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 pigeon pea 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 pigeon pea milling efficiency and produce consistent end products.

Performance evaluation of continuous pre-milling treated

Pigeon pea 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 pigeon pea

Sl	Run	Moisture content % (w.b.)	Power level %	Treatment Time	Dehulling yield %	Dhal yield %	Dehulling loss %	Temperature (ºC)
11	1	11.5	100	1.0	46.95	62.44	8.97	88.8
1	2	10.0	100	1.5	54.24	74.55	9.09	93.0
2	3	13.0	100	1.5	46.97	67.76	8.48	99.8
9	4	11.5	100	2.0	57.84	65.55	11.19	96.7
15	5	11.5	80	1.5	42.89	66.30	7.89	76.6
10	6	11.5	60	2.0	39.74	63.77	9.71	72.2
5	7	10.0	80	2.0	48.30	70.51	8.42	90.8
4	8	13.0	60	1.5	35.98	50.71	5.79	71.0
3	9	10.0	60	1.5	41.13	66.41	6.72	35.3
12	10	11.5	60	1.0	27.96	44.04	6.69	60.0
16	11	11.5	80	1.5	43.51	67.95	7.82	74.9
8	12	13.0	80	1.0	41.13	55.85	6.79	72.8
7	13	10.0	80	1.0	43.29	68.87	7.81	63.8
13	14	11.5	80	1.5	41.06	66.60	7.42	73.9
17	15	11.5	80	1.5	38.87	68.00	7.83	72.0
14	16	11.5	80	1.5	40.64	69.93	8.02	73.7
6	17	13.0	80	2.0	47.12	60.34	7.17	97.5

Effects of continuous microwave treatments on dehulling parameters of pigeon pea

Dehulling yield

The dehulling yield of pigeon pea was obtained between 27.96% and 57.84% during different treatment combinations. The minimum dehulling yield (27.96%) was obtained at 11.5% moisture content, 60% power level, and 1 min treatment time in the developed continuous pre-milling treater which was found to be about 2.07 times less than the maximum dehulling yield (57.84%) obtained at 11.5% moisture content, 100% power level, and 2 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 43.58% to 59.42%, 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) [20]; it increases dehulling effectiveness. A similar trend was observed by Joyner and Yadav (2015) [1] for treating black gram in continuous hydrothermal treater. The dehulling yield initially decreased with increasing moisture content from 43.58% to 39.96% and then increased again to 41.26% 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) [25] 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 pigeon pea.

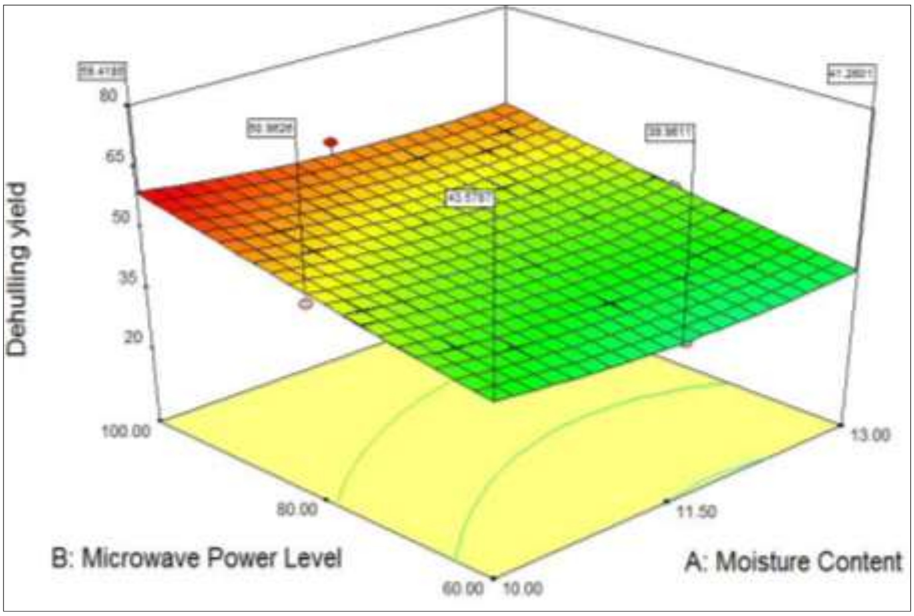

Fig 1: Cumulative effect of moisture content and microwave power level on dehulling yield of pigeon pea

It was observed from Fig. 2 that the dehulling yield increased as increasing from 35.40% to 52.04%, 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) [20], and these findings were correlated with this study. The dehulling yield increased as increasing treatment time from 1 min to 2 min from 35.40% to 43.57% 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. 2 demonstrates the cumulative effect of microwave power level and treatment time on the dehulling yield of pigeon pea.

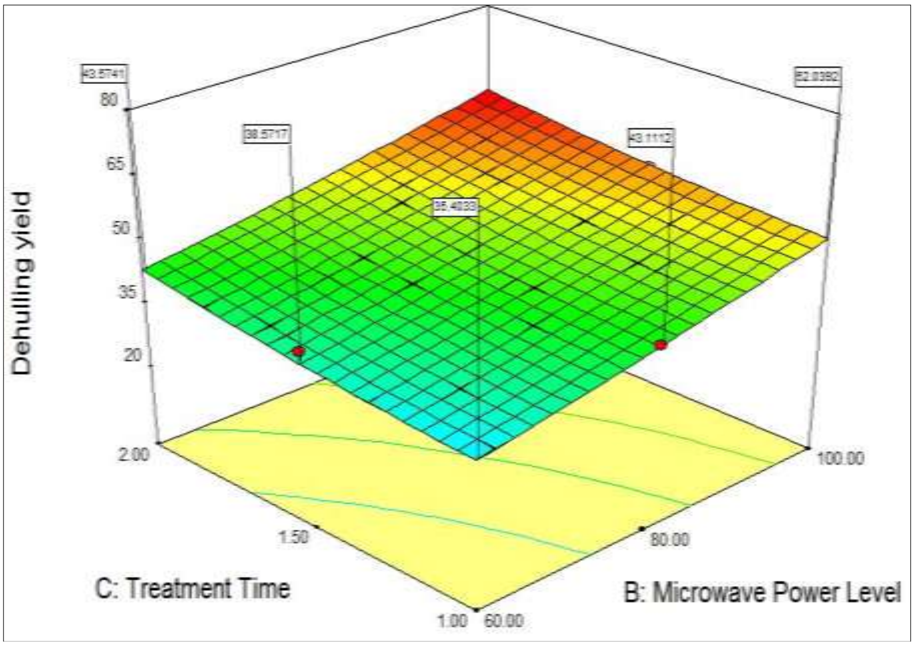

Fig 2: Cumulative effect of microwave power level and treatment time on dehulling yield of pigeon pea

$$\text{Dehulling yield} = 41.94 + 6.11A + 7.12B + 4.45C - 1.06AB + 0.49AC - 0.22BC + 10.05A^2 + 0.67B^2 + 1.05C^2 \quad (1)$$

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 (8.48) which is greater than the tabulated F value (0.51), 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 15.21 and 5.95 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 pigeon pea

Source	Sum of Squares	df	Mean Square	F Value	P-Value Prob > F
Model	678.07	9	75.34	8.48	0.0051^{s}
Linear terms					
A-Moisture content	8.67	1	8.67	0.98	0.3560
B-Microwave power level	135.14	1	135.14	15.21	0.0059^{s}
C-Treatment time	52.90	1	52.90	5.95	0.0448^{s}
Interaction terms					
AB	1.12	1	1.12	0.13	0.7326
AC	0.24	1	0.24	0.027	0.8741
BC	0.20	1	0.20	0.022	0.8855
Quadratic terms					
A^2	26.56	1	26.56	2.99	0.1274
B^2	1.91	1	1.91	0.22	0.6566
C^2	4.68	1	4.68	0.53	0.4915
Residual	62.19	7	8.88		
Lack of Fit	48.42	3	16.14	4.69	0.0848^{ns}
Pure Error	13.77	4	3.44		
Cor Total	740.26	16			

Dhal yield: The dhal yield of pigeon pea was obtained between 44.04% and 74.55% during different treatment combinations. The minimum dhal yield (44.04%) was obtained at 11.5% moisture content, 60% power level, and 1 min treatment time in the developed continuous pre-milling treater which was found to be about 0.59 times less than the maximum dehulling yield (74.55%) 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 59.82% to 72.54%, the power level for the entire range from 60% to 100% power level. Due to its higher moisture content, the dhal yield decreased as moisture content increased from 59.82% to 50.95%. The minimum dhal yield was observed at a 60% power level instead of 100%. The declining trend might be linked to the rising temperature and moisture content of the grains, which helped destroy the bindings of gums and mucilages between the seed coat and cotyledon. This result offers ease of dehulling (Kurien 1981; Phirke *et al* 1996; Sokhansanj and Patil 2003) [22, 15, 20]. Also, the grains expand to a larger size with increased moisture, and the cotyledons shrink more than the seed coat following pre-treatment, subsequent in a loosening of the husk that facilitates simpler dehulling. Kurien and Parpia (1968) [26] noticed a similar result when pigeon pea was preheated with hot air. Fig. 3 demonstrates the cumulative effect of moisture content and microwave power level on the dhal yield of pigeon pea.

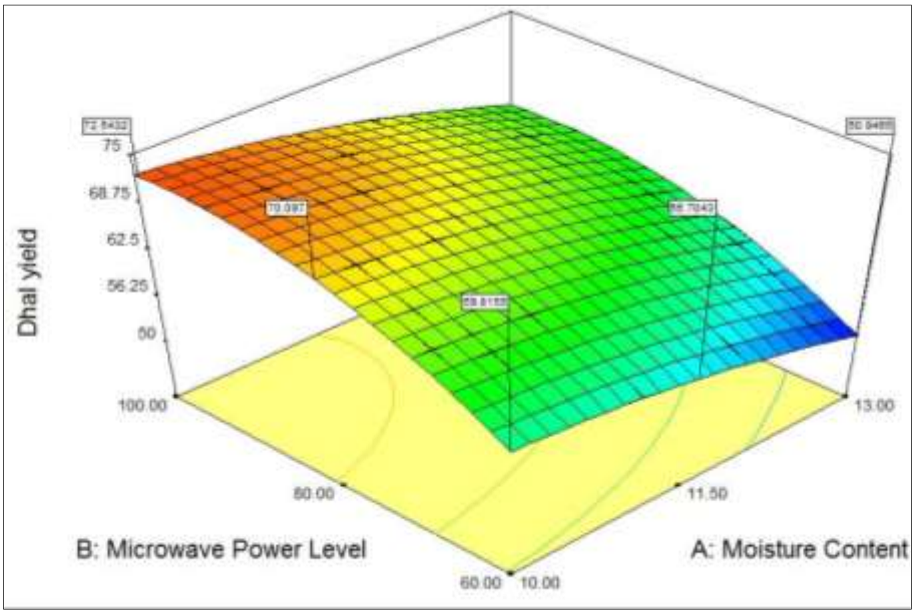

Fig 3: Cumulative effect of moisture content and microwave power level on dhal yield of pigeon pea

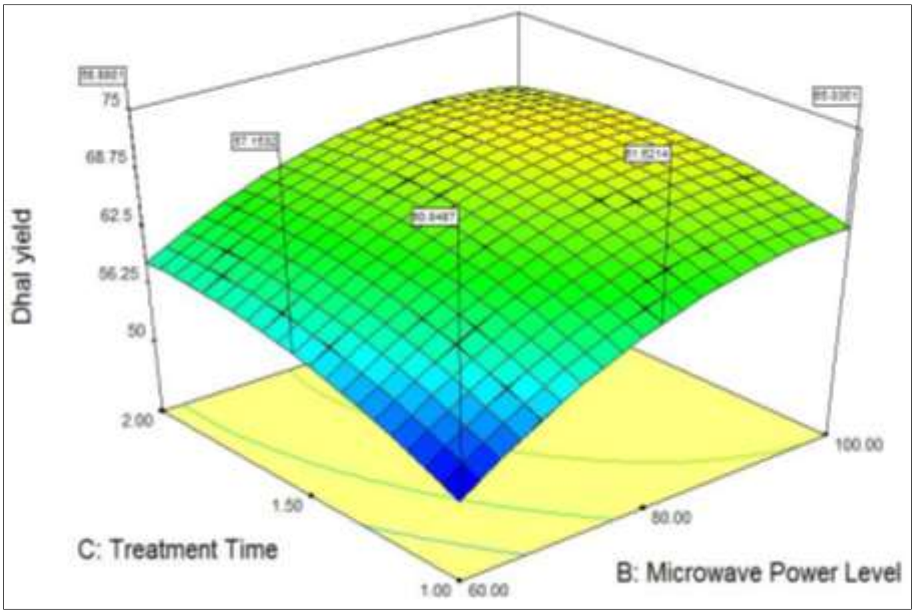

Fig 4: Cumulative effect of microwave power level and treatment time on dhal yield of pigeon pea

It was observed from Fig. 4 that the dhal yield increased as increasing from 50.85% to 65.04%, the power level for the entire range from 60% to 100% power level. The dhal yield increased as increasing treatment time from 1 min to 2 min from 50.85% to 58.88% 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%. As previously described, the increased dhal production with increasing microwave pre-milling treatment settings may result from the increasing temperature and grain absorption. The observed link between the hull and cotyledon of soybeans subjected to a 93 °C, 15-minute, hot-air treatment was found to be broken following previously published investigations (Sokhansanj and Patil

2003) [20] and exposure of black gram at a temperature of 92±2 °C for 10–15 min in steam caused in increased dhal yield to a maximum of 70.2% (Tiwari *et al*. 2010) [18]. Fig. 4 demonstrates the cumulative effect of microwave power level and treatment time on the dhal yield of pigeon pea.

$$\text{Dhal yield} = 63.07 - 9.83A + 6.65B + 4.33C - 0.55AB + 1.43AC - 4.16BC - 0.91A^2 - 5.17B^2 - 3.64C^2 \quad (2)$$

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 (8.15) 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 are 9.63, interaction terms of microwave power level and treatment time are 5.64, and quadratic terms of microwave power level are 9.20 with P values of less than 0.05, showing that the B ($p<0.05$), BC ($p<0.05$), and B^2 ($p<0.05$) are extremely significant terms.

Table 3: Analysis of variance for dhal yield of pigeon pea

Source	Sum of Squares	df	Mean Square	F Value	P-Value Prob > F
Model	897.87	9	99.76	8.15	0.0057^s
Linear terms					
A-Moisture content	22.48	1	22.48	1.84	0.2174
B-Microwave power level	117.88	1	117.88	9.63	0.0172^s
C-Treatment time	50.08	1	50.08	4.09	0.0828
Interaction terms					
AB	0.30	1	0.30	0.024	0.8806
AC	2.03	1	2.03	0.17	0.6959
BC	69.06	1	69.06	5.64	0.0492^s
Quadratic terms					
A^2	0.22	1	0.22	0.018	0.8974
B^2	112.56	1	112.56	9.20	0.0190^s
C^2	55.65	1	55.65	4.55	0.0704
Residual	85.66	7	12.24		
Lack of Fit	77.38	3	25.79	12.46	0.0169^s
Pure Error	8.28	4	2.07		
Cor Total	983.53	16			

Dehulling loss

The dehulling loss of pigeon pea was obtained between 5.79% and 11.19% during different treatment combinations. The minimum dhal yield (5.79%) was obtained at 13% moisture content, 60% power level, and 1.5 min treatment time in the developed continuous pre-milling treater which was found to be about 1.93 times less than the maximum dehulling loss (11.19%) obtained at 11.5% moisture content, 100% power level and 2 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 8.72% to 10.33%, the power level for the entire range from 60% to 100% power level. The dehulling loss increased initially by increasing moisture content from 8.72% to 9.01% up to 11.5% and then decreased to 7.47% with increasing moisture content in the given range due to its conductance for microwave treatment. The reduction in dehulling loss with increased microwave power might be related to the shorter dehulling duration. This was consistent with the findings of Deshpande *et al*. (2007). They found that the traditional dehulling of pigeon pea decreased the percentage of dehulling loss when the dehulling duration reduced from 45 to 25 s. Fig. 5 demonstrates the cumulative effect of moisture content and microwave power level on the dehulling loss of pigeon pea.

It was observed from Fig. 6 that the dehulling loss increased as increasing from 7.11% to 9.67%, the power level for the entire range from 60% to 100% power level. The dehulling loss increased as increasing treatment time from 1 min to 2 min from 7.11% to 9.03% due to the severity of longer treatments. The minimum dehulling yield was observed at a 60% power level instead of 100%. The reduction in dehulling loss as microwave power level increases may be due to the decreased dehulling time. This was consistent with the findings of Deshpande *et al.* (2007), who found that the traditional dehulling of pigeon pea resulted in a decrease in dehulling time from 45 to 25 s. Fig. 6 demonstrates the cumulative effect of microwave power level and treatment time on the dehulling loss of pigeon pea.

$$\text{Dehulling loss} = 6.39 - 4.69A + 1.18B + 0.72C + 0.16AB - 0.12AC - 0.20BC - 3.74A^2 + 0.66B^2 + 0.69C^2 \quad (3)$$

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 (6.74) which is less than the tabulated F value (0.99), 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 moisture content and microwave power level are 13.08, 9.53, and quadratic terms of moisture content are 9.40 with P values of less than 0.05, showing that the A ($p<0.05$), B ($p<0.05$), and A^2 ($p<0.05$) are extremely significant terms.

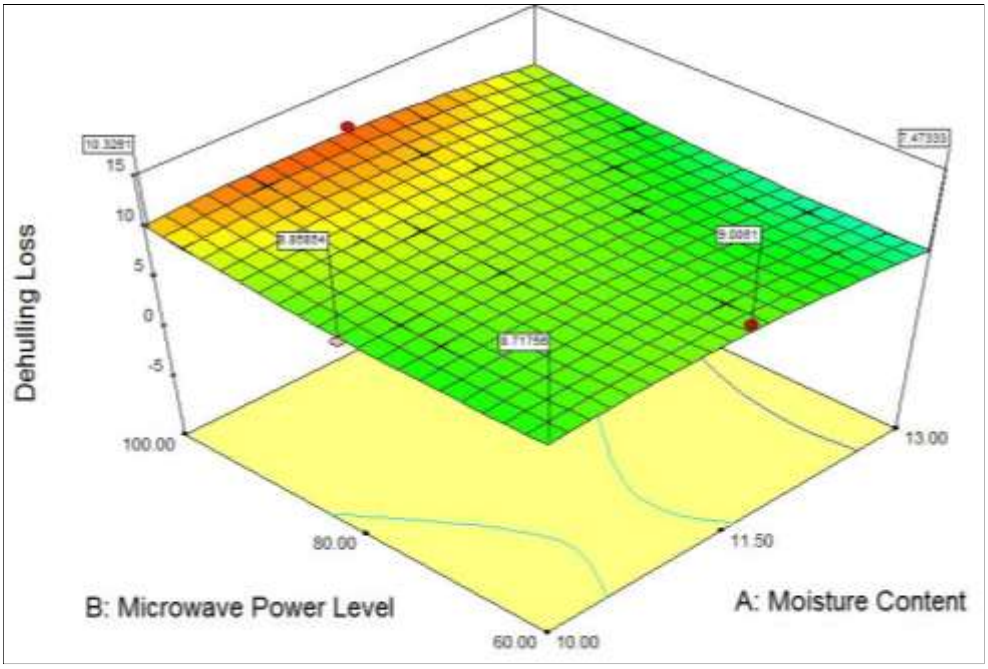

Fig 5: Cumulative effect of moisture content and microwave power level on dehulling loss of pigeon pea

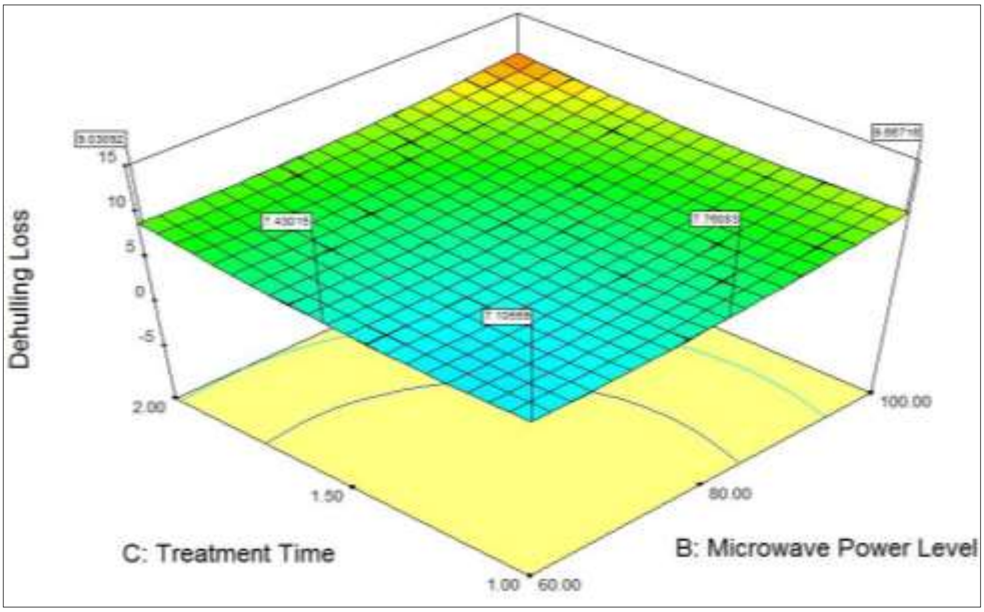

Fig 6: Cumulative effect of microwave power level and treatment time on dehulling loss of pigeon pea

Table 4: Analysis of variance for dehulling loss of pigeon pea

Source	Sum of Squares	df	Mean Square	F Value	P-Value Prob > F
Model	23.73	9	2.64	6.74	0.0099[s]
Linear terms					
A-Moisture content	5.11	1	5.11	13.08	0.0086[s]
B-Microwave power level	3.73	1	3.73	9.53	0.0176[s]
C-Treatment time	1.39	1	1.39	3.55	0.1017
Interaction terms					
AB	0.026	1	0.026	0.065	0.8054
AC	0.013	1	0.013	0.034	0.8593
BC	0.16	1	0.16	0.41	0.5428
Quadratic terms					
A^2	3.68	1	3.68	9.40	0.0182[s]
B^2	1.82	1	1.82	4.66	0.0676
C^2	1.98	1	1.98	5.06	0.0592
Residual	2.74	7	0.39		
Lack of Fit	2.54	3	0.85	16.73	0.0100[s]
Pure Error	0.20	4	0.051		
Cor Total	26.47	16			

Temperature

The temperature of pigeon pea was obtained between 71 °C and 99.8 °C during different treatment combinations. The minimum temperature (71 °C) was obtained at 10% moisture content, 60% power level, and 1.5 min treatment time in the developed continuous pre-milling treater which was found to be about 0.71 times less than the maximum temperature (99.8 °C) obtained at 13% 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 51.4 °C to 99.1 °C, and the power level for the entire range was from 60% to 100%. The increase in grain temperature with increasing moisture content and microwave power level may be related to the increased thermal conductivity of grains with increased moisture. The temperature increased as the moisture content increased from 51.4 °C to 79.5 °C 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 treated grains were higher temperatures at higher power levels with higher dosages for grains to absorb higher radiations. Fig. 7 demonstrates the cumulative effect of moisture content and microwave power level on the temperature of pigeon pea.

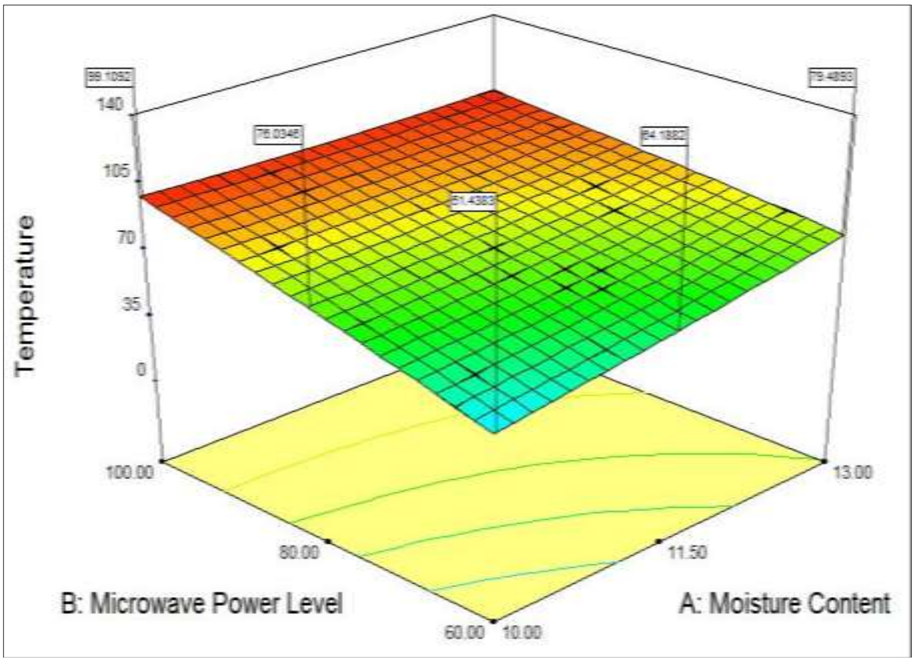

Fig 7: Cumulative effect of moisture content and microwave power level on temperature of pigeon pea

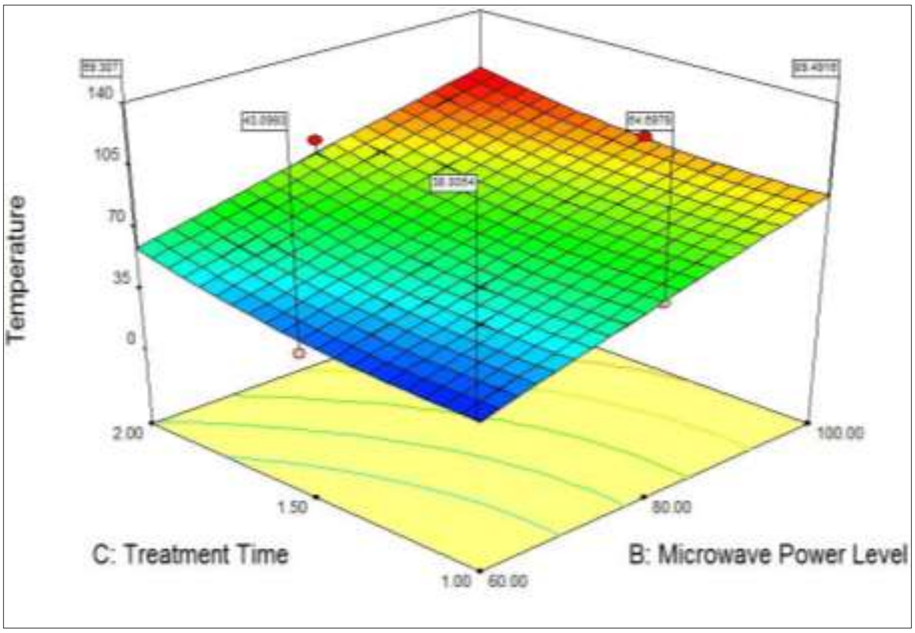

Fig 8: Cumulative effect of microwave power level and treatment time on the temperature of pigeon pea

It was observed from Fig. 8 that the temperature increased as increasing from 38 ºC to 89.5 ºC, and the power level for the entire range was from 60% to 100% power level. The temperature increased as increasing treatment time from 1 min to 2 min from 38 ºC to 59.3 ºC due to the severity of longer treatments. The minimum temperature was observed at a 60% power level instead of 100%. The increase in grain temperature with increasing moisture content and microwave power level may be related to the greater heat conductivity of grains with higher moisture content. The temperature increased as the moisture content increased from 51.4 ºC to 79.5 ºC in the entire range due to its higher residence time for continuous microwave pre-milling treatments in the treatment chamber. Fig. 8 demonstrates the cumulative effect of microwave power level and treatment time on the temperature of pigeon pea.

$$\text{Temperature} = 82.67 + 19.26A + 10.25B + 8.40C - 14.45AB - 1.15AC - 1.07BC + 4.71A^2 - 0.62B^2 + 5.83C^2 \quad (4)$$

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 (8.29) which is greater than the tabulated F value (3.84), 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. 4 displays that F values for linear terms of microwave power level are 5.39 with P values of less than 0.05, showing that the B ($p<0.05$) is extremely significant.

Table 5: Analysis of variance for temperature of pigeon pea

Source	Sum of Squares	df	Mean Square	F Value	P-Value Prob > F
Model	3878.08	9	430.90	8.29	0.0054[s]
Linear terms					
A-Moisture content	86.27	1	86.27	1.66	0.2386
B-Microwave power level	280.17	1	280.17	5.39	0.0433[s]
C-Treatment time	188.16	1	188.16	3.62	0.0988
Interaction terms					
AB	208.80	1	208.80	4.02	0.0851
AC	1.32	1	1.32	0.025	0.8778
BC	4.62	1	4.62	0.089	0.7742
Quadratic terms					
A^2	5.84	1	5.84	0.11	0.7473
B^2	1.63	1	1.63	0.031	0.8644
C^2	142.99	1	142.99	2.75	0.1411
Residual	363.81	7	51.97		
Lack of Fit	352.38	3	117.46	41.11	0.0018[s]
Pure Error	11.43	4	2.86		
Cor Total	4241.89	16			

Conclusion

The optimized continuous pre-milling treater offers several benefits for pigeon pea processing. By achieving uniform conditioning, the treater enhances milling efficiency, reduces energy consumption, and increases product yield. The resulting pigeon pea 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 pigeon pea 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 pigeon pea 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 pigeon pea processing holds promise in enhancing milling outcomes and product quality. By offering a controlled and uniform pre-milling treatment, the treater contributes to efficient pigeon pea processing and elevates the overall value of pigeon pea-derived products. As food industries seek sustainable and innovative solutions, the treater's potential to revolutionize pigeon pea processing underscores its significance in shaping the future of food production and nutrition the best condition was obtained for pigeon pea with 10% moisture content treated with the microwave power level of 90% for about 1.5 min to achieve a dehulling yield of 49.15%, dhal yield of 74.55%, dehulling loss of 7.67%.

References

1. Agrawal S, Mangaraj S, Kapor T, Katiyar SK. Effect of premilling treatment and grades of carborundum rollers on milling of pulses. 15th IFCON- 2003, CFTRI, Mysore; c2003.
2. Anon. Agricultural statistics at a glance (2004). Directorate of economics and statistics, Ministry of Agriculture Government of India. New Delhi; c2004.
3. Chacko J, Saxena RP, Kumbhar BK, Agrawal US. Pigeon pea milling: A status report. National seminar on emerging trends in processing, handling, storage and by-product utilization of pulses and soyabean. GBPUAT, Pantnagar; c2001.
4. Divekar MT, Karunakaran C, Lahlali R, Kumar S, Chelladurai V, Liu X, *et al.* Effect of microwave treatment on the cooking and macronutrient qualities of pulses. International Journal of Food Properties; c2016. ISSN: 1094-2912 (Print) 1532-2386;
5. Dronachari1 M, Yadav BK. Application of Microwave Heat Treatment in Processing of Pulses. Journal of Academia and Industrial Research (JAIR) Youth Education and Research Trust (YERT); c2015. jairjp.com, ISSN: 2278-5213 401
6. Goyal RK, Vishwakarma RK, Wanjari OD. Optimisation of the pigeon pea dehulling process. Research Paper: PH-Postharvest Technology. 2007;9(25):1941-1947.

7. Goyal RK, Vishwakarma RK, Omkar. Optimisation of process parameters and mathematical modelling for dehulling of pigeon pea. Food science Technology. 2008;44(1):36-41.
8. Goyal RK, Wanjari OD, Vishwakarma RK. Optimising of pigeon pea dehulling process. 2007;99(1):56-61.
9. Mangaraj S, Agrawal S, Kapur T, Kulkarni SD. Effect of pre-milling treatment on cooking quality of pulses. 38th ISAE convention, Dapoli; c2004.
10. Mangaraj S, Agrawal S, Kapur T, Kulkarni SD. Effect of pre-milling treatment and abrasive rollers on milling of pulses. Journal of Agricultural Engineering. 2004;41:10-15.
11. Mangaraj S, Kapur T. Milling studies of pulses using different pre-treatment and abrasive roller assembly. Agricultural Engineering Today. 2005;29:64-70.
12. Mangaraj S, Singh KP. Optimization of machine parameters for milling of pigeon pea using RSM. Food Bioprocess and Technology; c2009. doi:10.1007/s 11947-008-021-x.
13. Murumkar RP, Borkar PA, Munje SS, Rathod PK, Rajput MR, Dhoke SM, *et al*. Effect of enzyme pretreatments on milling of pigeon pea. International journal of science, Environment. 2016;5(6):4029-4051.
14. Muttaluri MK, Verma RC. Microwave Assisted Dehulling of Black Gram (*Vigna mungo* L). International Journal of Science, Environment and Technology. 2017;6(1):472-482. ISSN 2278-3687 (O).
15. Phirke PS, Bhole NG. Response surface modelling and optimization of dehulling of pigeon pea with different pre-treatments and conditions. Journal of Food Science Technology. 1996;33:47-52.
16. Singh D, Sokhansaraj S. Concave mechanization and chemical treatment for dehulling of pigeon pea, Agricultural Mechanization in Asia, Africa and Latin America. 1984;15:58.
17. Srivastava S. Comparison of various pre- milling treatment of pigeon pea (*Cajanus cajan* L.) grain on a laboratory mill, M.Tech (Agricultural Engineering) Thesis, G.B. Pant University of Agricultural and Technology, Pantnagar; c1999.
18. Tiwari BK, Jagan Mohan R, Venkatachalapathy N, Anand, M Surabi, Alagusundaram A, *et al*. Optimization of hydrothermal treatment for dehulling of pigeon pea, Food research international. 2010;43(2):496-500.
19. Singh D. Female judgment of male attractiveness and desirability for relationships: Role of waist-to-hip ratio and financial status. Journal of personality and social psychology. 1995 Dec;69(6):1089.
20. Sokhansanj SH, Patil RT. Dehulling and splitting pulses. Handbook of postharvest technology: Cereals, fruits, vegetables, tea, and spices. 2003;93:397.
21. 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.
22. Kurien G, Cole I. Primary carcinoma of the trachea. Clinical Otolaryngology & Allied Sciences. 1981 Jun;6(3):197-204.
23. Ratnam BV, Narasimha Rao M, Damodar Rao M, Subba Rao S, Ayyanna C. Optimization of fermentation conditions for the production of ethanol from sago starch using response surface methodology. World Journal of Microbiology and Biotechnology. 2003 Jul;19:523-6.
24. Choudhary DN, Sahay GR, Singh JN. Antifertility and cannibalistic properties of some mycotoxins in albino rats. Journal of Food Science and Technology (Mysore). 1994;31(6):497-9.
25. 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.
26. Kurien PP, Parpia HA. Pulse milling in India. I-Processing and milling of Tur, Arhar (*Cajanus cajan* Linn). Journal of Food Science and Technology (Mysore). 1968;5(4):203-7.