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Performance evaluation of innovative turmeric boiling system

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Abstract
An innovative turmeric boiling system based on utilization of steam for curing of turmeric was developed to reduce the fuel requirement, support in steam saving and reduce the overall time and labor requirement for turmeric processing. A mild steel pressure vessel was designed and developed to hold around 150 kg raw turmeric rhizomes. The fabricated pressure vessel was connected to a steam boiler by means of steam pipe for curing raw rhizomes. The developed vessel comprised of loading mechanism, unloading mechanism, pressure gauge, safety valve, steam release valve along with steam distribution system for uniform spreading of steam within the pressure vessel. The developed system was run with optimized conditions of steam pressure and holding time (16 psi & 1.10 minutes) for processing raw turmeric rhizomes. It was found that turmeric powder with maximum recovery (19.44%), color characteristics (L=53.65, a=15.42, b= 38.34) and maximum volatile oil (6.39%), curcumin content (4.18%) and oleoresin content (13.99%) was obtained using the innovative turmeric boiling system.

Keywords: Turmeric, boiling, steam, drying, curcumin

1. Introduction

Turmeric (*Curcuma longa*) plant is grown as an annual crop for its rhizome. Turmeric is commercially cultivated because the processed dried rhizomes are in high demand. Turmeric finds its requirement in large variety of uses due to its constituent essential oil and curcumin and oleoresin. Turmeric is an essential ingredient of curry, used in religious festivals, as a flavoring agent, a natural dye for food, textile and cosmetics, also as an insect repellant and in many traditional health remedies. Turmeric has been found to be anti-inflammatory (Chainani 2003) [7], antimicrobial (Arutselvi *et al.* 2012) [3], antioxidant (Menon and Sudheer 2007) [12], anti mutagenic (Jayaprakasha *et al.* 2002) [9] and anti-cancer (Bar *et al.* 2010) [6] whereas curcumin specifically is used as a nutraceutical (Joe *et al.* 2004) [11].

Globally the major turmeric cultivation area is in India which constitutes 82% of world production followed by China, Myanmar and Bangladesh (Anantkawlas 2014) [1]. Raw turmeric rhizomes undergo a number of post harvest processing operations like pre-cleaning, washing, boiling (curing), drying, polishing and grinding before being available to the customers (Anon 2008). Boiling softens the rhizomes and removes the raw odor. Also during boiling, the starch is gelatinized, which reduces the drying time required and the color is uniformly distributed throughout the rhizome (Jayashree *et al.* 2015) [10]. Starch gelatinization not only facilitates rapid drying but also provides protection against insect attack during storage (Gounder and Lingamallu 2012) [8].

Farmers using the traditional boiling technique undertake open boiling of turmeric in water in an iron vessel. This method has drawbacks as it leads to overcooking of rhizomes at the bottom of vessel and undercooking at the top, loss of curcumin and oleoresin while removing rhizomes from the vessel due to injuries occurred by rubbing and bruising, high labor requirement, losses in handling, inefficient use of fuel, requires more time and increases cost of processing (Shinde *et al.* 2011) [14]. Another type of technique uses steam boiling where steam is produced in the same vessel in which turmeric is to be boiled. Every time during unloading of boiled rhizomes, steam pressure has to be reduced to zero so that vessel cover can be removed and boiled turmeric taken out. This affects the efficiency of the system and is time consuming process. Every time the fresh batch is put into the vessel, steam has to be generated again. Although the hydro-thermal processing of rhizomes is completed in around 20 minutes but in this type of system, complete process for boiling one batch takes nearly 2-3 hours and this process is quite labour intensive. (Patil and Chhapkhane 2013) [13].

The quality of turmeric depends on its color and flavor, which is given by curcumin, volatile oil and oleoresin. The final quality of turmeric is very much dependent on boiling method employed during post harvest processing of the material.

The boiling techniques which are prevalent are inefficient and also the time of boiling and steam pressure during curing is not standardized. This causes a deviation in recovery and value of turmeric powder obtained from same variety but from different processing technique or system.

To overcome all the demerits of the existing techniques current study laid emphasis on designing, fabrication and testing of novative turmeric boiling system. The mechanism used a separate steam generation unit which supplied steam to a pressure vessel holding raw rhizomes. The system aimed at saving steam, reducing the fuel requirement of the process and help in uniform cooking along with reducing the overall time and labour requirement.

2. Materials and Methods

2.1 Raw material

Raw turmeric rhizomes of variety Punjab Haldi-1 was procured from a farmer of Ludhiana district in Punjab. The variety having curcumin content (2-5%), oleoresin content (10-16%), volatile oil (5-8%) and yield (27-30 t/ha) was used for undertaking present studies.

2.2 Processing of turmeric rhizomes

The processing of turmeric was done starting from precleaning and washing, grading, boiling at varying steam pressure and holding time, drying, polishing and grinding the polished rhizomes to get the turmeric powder. The laboratory scale boiling of the turmeric samples was done in an autoclave with 5 kg of raw rhizomes for each treatment. Steam pressure in the autoclave was allowed to increase to a specific value using the pressure controller and the required pressure was maintained for a particular holding time. To optimize the boiling conditions i.e steam pressure and holding time, various combinations of steam pressure (10-15-20 psi) and holding time (0-5-10-15 minutes) were used for hydrothermal treatment of turmeric. The boiled rhizomes were dried in a solar dryer assisted before polishing. The dried rhizomes were then polished using a polishing machine which removed the outer dark colored skin and turned the rhizomes bright yellow. The polished rhizomes were then pulverized into fine powder using a hammer mill grinder. The final product obtained was then analyzed for qualitative and quantitative parameters.

2.3 Experimental design and statistical analysis

The experimental data recorded was done as per completely randomized block design. The total number of treatments was 12. The data obtained was used as historical data for regression analysis and different models were fitted. The responses obtained for the different treatments were then analyzed by generating the analysis of variance tables and the effect of linear, quadratic and the interaction terms among the process parameters were studied using Design Expert software. The significance of all the terms in the polynomial was determined statistically by calculating the F-value and the significance of the F value was assessed at 1% and 5% level of significance. The dependent variables (Y) polishing loss, grinding loss, recovery, color values; volatile oil, curcumin and oleoresin content were governed by the equation:

$$Y = b_o + b_1A + b_2B + b_3A^2 + b_4B^2 + b_5AB + \varepsilon$$

Numerical and graphical optimization with historical data was performed to reach the optimum set of parameters for turmeric boiling using Design Expert software with following goals: Polishing Loss (%) : Minimum, Grinding Loss (%) : Minimum, Recovery (%) : Maximum, L value : Maximum, a value : Maximum, b value : Maximum, Volatile oil (%) : Maximum, Curcumin content (%) : Maximum and Oleoresin content (%) : Maximum. The developed turmeric boiling system was then run on the optimized set of parameters to get the best result.

2.4 Determination of quality characteristics of pulverized turmeric powder

2.4.1 Determination of polishing loss

The polishing loss of turmeric is the loss of dried turmeric mass in terms of the removal of rhizome skin. Initial weight of dried unpolished rhizomes loaded in the polisher and the weight of the polished rhizomes after processing was used to calculate the polishing loss. The following formula is used to calculate the polishing loss (%).

$$\text{Polishing loss}(\%)=\frac{\text{Weight of dried rhizomes-Weight of polished rhizomes}}{\text{Weight of dried rhizomes}}\times 100$$

2.4.2 Determination of color

Color of the turmeric powder was measured using the Hunter Lab Miniscan XE Plus Colorimeter. The colorimeter was calibrated using standard white and black tiles provided for calibration of the instrument before measuring the color parameters of the samples. The colorimeter expressed the color in Hunter Lab units *L*,*a*,*b*.

2.4.3 Determination of grinding loss

Grinding loss is the loss during the pulverization of dried polished turmeric rhizomes polishing into fine quality powder. The initial weight of polished rhizomes fed to the grinder and final weight of the powder obtained was used to calculate the grinding loss. The following formula was used to calculate the grinding loss (%).

$$\text{Grinding loss}(\%)=\frac{\text{Weight of polished rhizomes-Weight of powder}}{\text{Weight of polished rhizomes}}\times 100$$

2.4.4 Determination of final recovery

The final recovery of the turmeric obtained after processing represented the pulverised turmeric powder obtained in comparison to the initial weight of raw turmeric processed. The following formula was used to calculate the final recovery (%).

$$\text{Final recovery}(\%)= 100-\frac{\text{Weight of raw turmeric-Weight of ground powder}}{\text{Weight of raw turmeric}}\times 100$$

2.4.5 Determination of volatile oil content

The volatile oil present in the turmeric was estimated by hydro-distillation using Clevenger distillation apparatus method as suggested by Gounder and Lingamallu (2012) [8].

2.4.6 Determination of oleoresin content

The oleoresin in the turmeric was extracted by using the Soxhlet apparatus. A 20gm sample of turmeric powder taken in a thimble was placed in the extractor and refluxing process was done for 6 hours. After completion of the process, a yellowish extract was obtained. The extract was then allowed to cool down and then filtered. Total volume of extract produced was noted down and 5 ml of this extract was transferred into a Petri dish. The excess methanol in the dish evaporated at room temperature leaving behind a gummy dark brown mass. The dried brown mass was weighed and the oleoresin content of the turmeric was calculated using the following formula.

$$\text{Oleoresin content}(\%)=\frac{W\times V}{5\times 20}\times 100$$

W = Weight of dried mass produced from 5ml of extract
V = Total volume of extract produced

2.4.7 Determination of curcumin content
The yellow colored extract produced by refluxing the solvent using the Soxhlet apparatus was used for the estimation of the curcumin in the turmeric (Bagchi 2012) [4]. An aliquot was made by diluting the extract with methanol in a flask. Methanol was kept as a blank and then absorbance of this aliquot was measured using the spectrophotometer at 425nm wavelength. Curcumin content was estimated by using the following formula.

$$\text{Curcumin content}(\%)=\frac{0.0025\times\text{Absorbance at 425nm}\times\text{Volume made up(ml)}\times\text{Dilution factor}\times 100}{0.42\times\text{Weight of sample(gm)}\times 1000}$$

2.5 Design of innovative turmeric boiling system
The pressure vessel having 150 kg capacity of holding raw turmeric rhizomes was designed, fabricated and tested. The turmeric holding vessel was designed based on the bulk density of the raw turmeric rhizomes. According to the holding capacity required the volume of the vessel was estimated. The pressure vessel was fabricated using mild steel. The volume was found by using the following formula:

$$\text{Volume of turmeric holding vessel}(m^3)=\frac{\text{Weight of turmeric to be boiled (kg)}}{\text{Bulk density of raw turmeric rhizomes}\left(\frac{kg}{m^3}\right)}$$

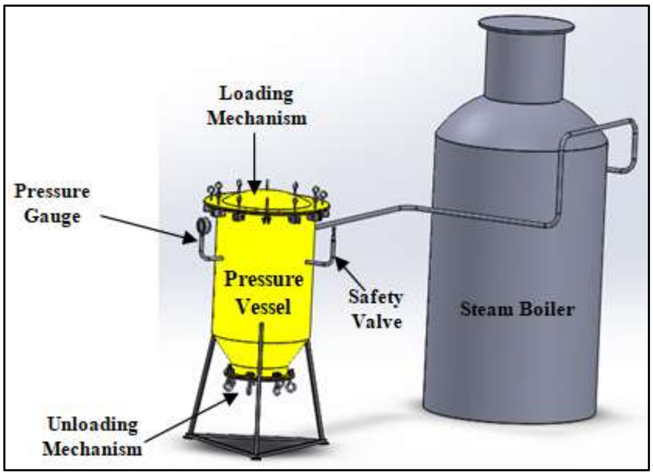

Fig 1: Two-dimensional sketch of turmeric boiling mechanism

Based on the volume of the required holding vessel, the height and diameter of the vessel were calculated**.** A hinged head was installed on the top of the vessel which could be opened during loading of the rhizomes. The diameter of the top head was kept equal to the diameter of the pressure vessel. For the removal of rhizomes after completion of the boiling process the unloading mechanism was fixed at the bottom of the vessel. The diameter of the unloading circular disc was approximately half the diameter of the pressure vessel. A pressure gauge was installed on the turmeric holding vessel to depict the steam pressure at which the turmeric was being treated. A spring loaded safety valve was also installed on the vessel to keep the steam pressure in the vessel up to safe limits and release any excess pressure. The valve prevented any damage to the loaded turmeric rhizomes as well. A pressure release valve was installed near the truncated bottom of the pressure vessel to remove the condensate produced in the vessel after the boiling process was completed. The steam from the boiler was distributed in the turmeric holding pressure vessel through the steam distribution assembly fitted in the center of the vessel.

2.6 Operation of innovative turmeric boiling system
The developed pressure vessel had the diameter 610 mm and 900 mm height and it was connected to a steam boiler for supply of steam. The steam boiler had a capacity of 200 kg/h which was fired using firewood as fuel.
The raw turmeric rhizomes were loaded into the holding vessel from the upper loading section and the loading door was then tightened. The steam supply valve was opened to allow high pressure steam enter the pressure vessel. The steam helped in curing the rhizomes at the optimized boiling conditions of steam pressure and holding time. After completion of boiling process, the steam supply was shut-off and the steam release valve near the bottom of the vessel was opened to remove the condensate and excess steam.
The lower unloading gate was then opened to remove the rhizomes from the pressure vessel. The obtained rhizomes were then analyzed for quality attributes.

3. Results and Discussion
3.1 Polishing Loss (%)
The polishing loss of the product varied from 5.39 to 7.11% (Table 1). The Model F-value of 6.13 (Table 2) implied that the model was significant. The term B was significant, whereas term A was not significant. The value of R^2 was 0.58 and the Predicted R^2 of 0.31 was in reasonable agreement with the Adjusted R^2 of 0.48 (Table 2).
The variation of the polishing loss with steam pressure and holding time were graphically represented in 3-D surface plots and contour plots (Fig 2). Maximum polishing loss of 7.11 per cent was recorded with 15 psi steam pressure and 15 minutes holding time and minimum polishing loss 5.39% was recorded 15 psi steam pressure and zero minutes holding time. It was observed that polishing loss appears to be decreasing with increase in steam pressure and increasing with increase in holding time.
The predicted model for polishing loss (%) can be described by the following equation in terms of coded factors:

Polishing loss (%) = 6.35667 + -0.08125 * A + 0.48 * B

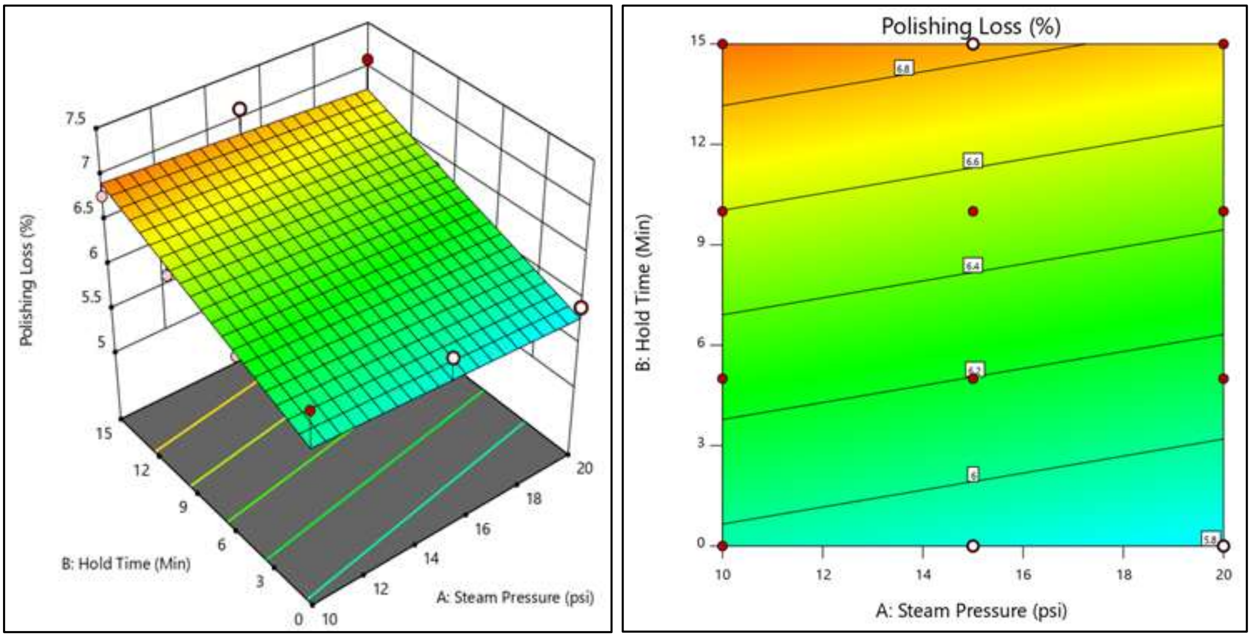

Fig 2: Response surface and contour plots for polishing loss (%) showing the effect of steam pressure and hold time

Table 1: Treatment combinations of historical data and responses for process parameters optimization

S. No.	Factors		Responses								
	A: Steam Pressure(psi)	B: Holding Time(min)	Polishing Loss (%)	Grinding Loss (%)	Recovery (%)	L value	a value	b value	Volatile oil (%)	Curcumin content (%)	Oleoresin content (%)
1	10	0	6.36	3.43	20.44	49.17	14.35	34.6	7.05	3.84	15.05
2	10	5	6.26	3.37	20.83	49.5	15.1	33.98	6.85	2.81	13.63
3	10	10	6.5	3.96	19.26	50.63	16.13	35.4	6.69	2.64	13.32
4	10	15	6.78	3.99	18.78	51.2	14.8	35.2	6.14	2.37	12.23
5	15	0	6.12	3.67	20.62	50.83	15.63	36.87	6.78	4.13	15.53
6	15	5	5.39	3.84	21.32	51.8	16.63	37.07	6.74	4.03	13.42
7	15	10	6.51	4.01	19.8	53.07	17.03	37.33	6.4	3.55	12.77
8	15	15	7.11	3.97	18.16	53.03	15.47	35.93	5.87	2.99	11.69
9	20	0	5.92	3.9	20.42	51.63	15.57	36.67	6.88	3.22	13.73
10	20	5	5.87	3.6	20.19	52.2	15.8	36.1	6.41	2.86	12.75
11	20	10	6.37	4.2	19.05	52.73	15.67	35.2	6.09	2.57	12.12
12	20	15	7.09	4.57	17.93	52.7	14.5	34.47	5.47	2.18	10.88

Table 2: The coefficients for the responses in actual level of variables and statistic parameters

Coefficients	Polishing loss (%)	Grinding loss (%)	Final recovery (%)	L value	a value	b value	Volatile oil (%)	Curcumin content (%)	Oleoresin content (%)
Intercept									
b_0	6.36	3.88	20.4	52.33	16.82	36.94	6.55	3.65	13.24
Linear									
b_1	-0.0813	0.19	-0.215	1.09*	0.145	0.41	-0.235*	-0.1038	-0.5938*
b_2	0.48*	0.2975	-1.2	0.9415*	-0.052	-0.34	-0.5255*	-0.5945*	-1.51*
Quadratic									
b_3			-0.3625	-0.9625*	-0.95*	-1.60*	0	-0.8637*	-0.3887
b_4			-0.7687	-0.2569	-1.13*	-0.25	-0.1856*	0.0506	0.2063
Interaction									
b_5				-0.261	-0.429*	-0.80*	-0.1245*	0.0878	-0.0307
F Value	6.13	11.98	12.48	35.16	12.11	10.40	60.01	22.01	23.25
R-Squared	0.58	0.73	0.91	0.97	0.91	0.90	0.98	0.95	0.95
Adj R-Squared	0.48	0.67	0.84	0.94	0.83	0.81	0.96	0.91	0.91
Pred R-Squared	0.31	0.51	0.64	0.83	0.64	0.61	0.88	0.74	0.81

*significant at 5% level of significance

3.2 Grinding loss (%)

The grinding loss of the product varied from 3.43 to 4.57% (Table 1). A linear model was fitted, and the model was significant. Both A and B were significant model terms. The value of R^2 was found to be 0.73 and the Predicted R^2 (0.51) was in reasonable agreement with the Adjusted R^2 (0.67) (Table 2). Maximum grinding loss of 4.57 per cent was recorded with 10 psi steam pressure and 10 minutes holding time and minimum polishing loss 3.43% was recorded 20 psi steam pressure and 15 minutes holding time.

The variation of the grinding loss (%) with steam pressure and holding time is graphically represented in 3-D surface plots and contour plots (Fig 3).

It was observed that grinding loss varied proportionally with both steam pressure as well as holding time, i.e. it increased with increasing values of both the factors.

The predicted model for grinding loss (%) can be described by the following equation in terms of coded factors:

Grinding loss (%) = 3.87583 + 0.19 * A + 0.2975 * B

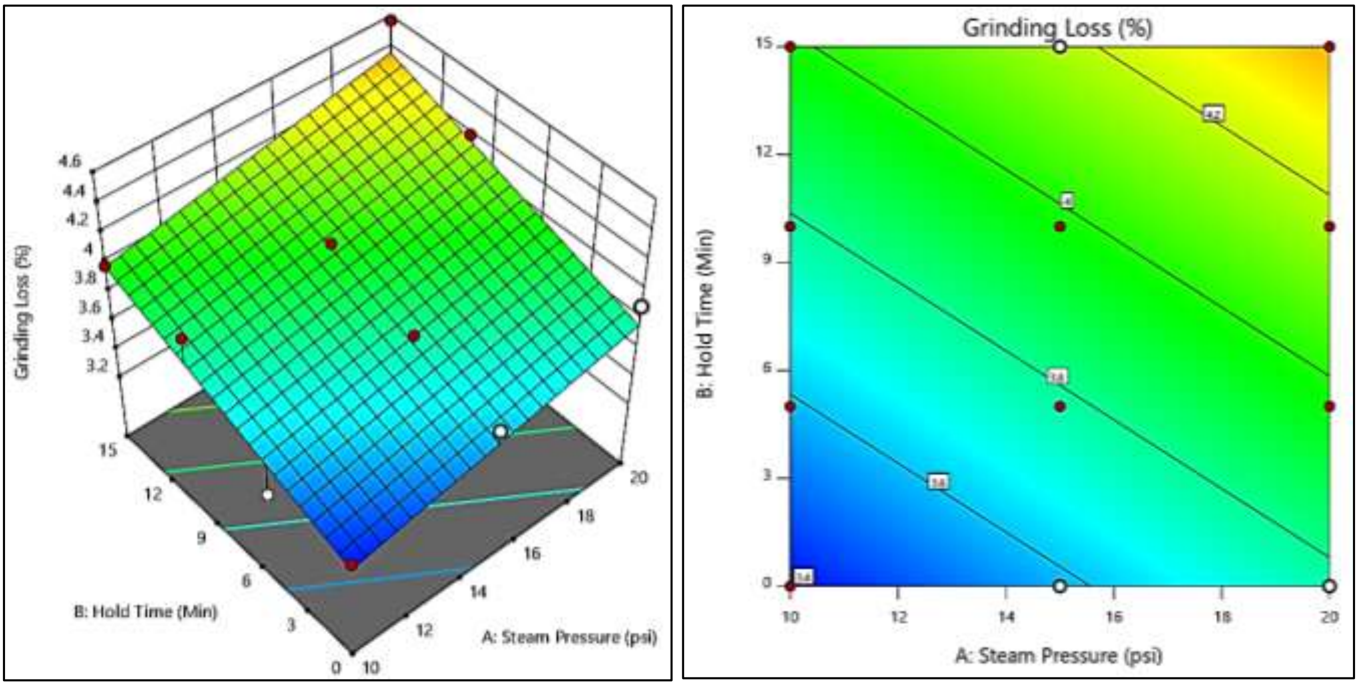

Fig 3: Response surface and contour plots for grinding loss (%) showing the effect of steam pressure and hold time

3.3 Final recovery (%)

Maximum recovery of 21.32 per cent was observed when turmeric was treated for 5 minutes at 15 psi steam pressure (Table 1). Lowest recovery was observed at steam pressure and holding time of 20 psi and 15 minutes respectively (17.93%). The Model F-value of 12.48 implied that the model was significant (Table 2). The value of R^2 was found to be 0.91, which implied that the model explained 91 per cent of the variability of the final recovery due to different process parameters. The Predicted R^2 (0.64) was in reasonable agreement with the Adjusted R^2 (0.84) (Table 2). The variation of the final recovery (%) with steam pressure and holding time is graphically represented in 3-D surface plots and contour plots (Fig 4). The final recovery (%) of turmeric appeared to decrease with the increase in steam pressure (A) as well as holding time (B). The interactive effect of steam pressure and holding time (AB) also lead to decrease in final recovery. The negative coefficients of quadratic terms of A as well as B indicate that final recovery decreased with increase in process parameters.

The predicted model for final recovery (%) can be described by the following equation in terms of coded factors:

Final recovery (%) = 20.4021 + -0.215 * A + -1.203 * B + -0.1545 * AB + -0.3625 * A^2 + -0.76875 * B^2

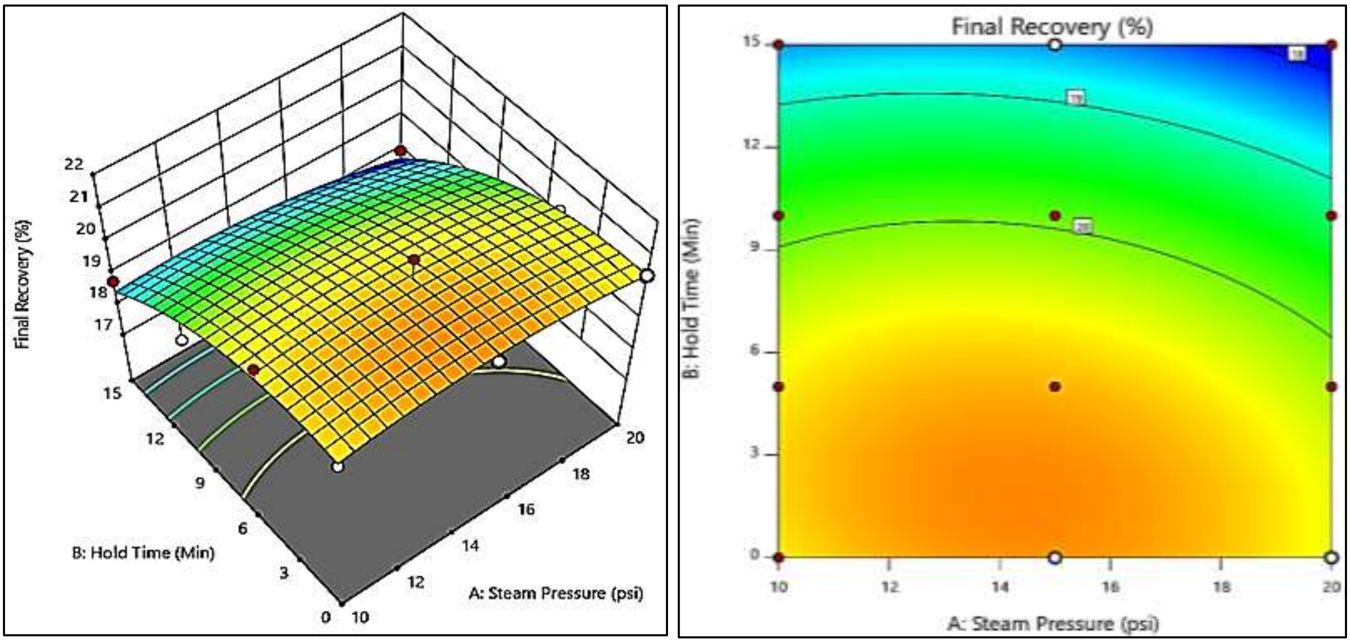

Fig 4: Response surface and contour plots for final recovery (%) showing the effect of steam pressure and hold time

3.4 Color values (L)

Maximum value 53.07 of luminosity (L) was observed at 15 psi steam pressure and 10 minutes holding time and minimum value of 49.17 at 10 psi steam pressure and zero minutes holding time respectively (Table 1). The Model F-value of 35.16 implies the model was significant. The Predicted R^2 (0.83) was in reasonable agreement with the Adjusted R^2 (0.94) (Table 2). The variation of the L value with steam pressure and holding time is graphically represented in 3-D surface plots and contour plots (Fig 5).The positive coefficients of the first order terms of A and B indicated that value of L increased with increase of these variables, whereas negative coefficients of interaction terms (AB) and quadratic terms indicated that it decreased with increase in these variables.

The predicted model for L value can be described by the following equation in terms of coded factors:

$$L\ value = 52.3252 + 1.095 * A + 0.9415 * B + -0.261 * AB + -0.9625 * A^2 + -0.256875 * B^2$$

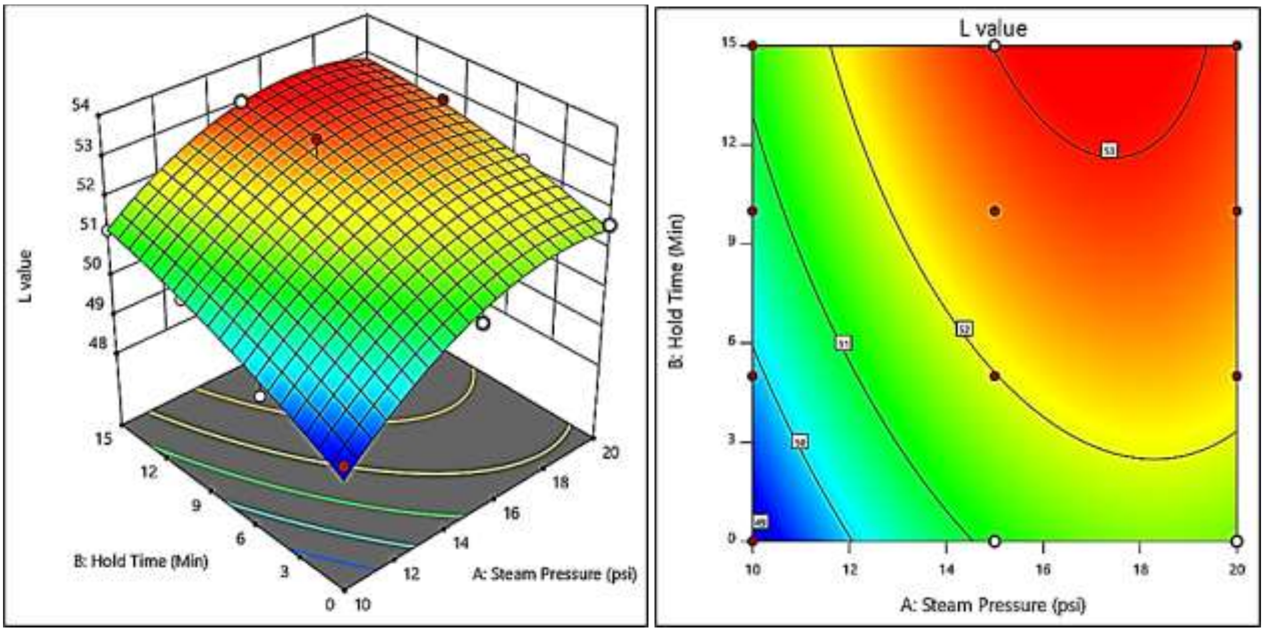

Fig 5: Response surface and contour plots for 'L' value showing the effect of steam pressure and hold time

3.5 Color values (a)

When turmeric was treated at 15 psi steam pressure for 10 minutes holding time, highest value (17.03) of intensity of redness (a) was obtained while the lowest intensity of redness (14.35) was obtained when turmeric was treated at 10 psi steam pressure and zero minutes holding time (Table 1). Model terms of AB (interaction), $A^2$and B^2 were significant at a 5% level of probability. The Model F-value of 12.11 implies the model was significant. The Predicted R^2 (0.64) was in reasonable agreement with the Adjusted R^2 (0.83) (Table 2). The variation of a value with steam pressure and holding time is graphically represented in 3-D surface plots and contour plots (Fig 6). The positive coefficient of first order term of A indicated that value of a increased with increase in this variable. The negative coefficients of first order term of B, interaction term (AB) and quadratic terms indicated that value of a decreased with increase in these variables.

The predicted model for a value can be described by the following equation in terms of coded factors:

$$a\ value = 16.8192 + 0.145 * A + -0.052 * B + -0.429 * AB + -0.95 * A^2 + -1.1325 * B^2$$

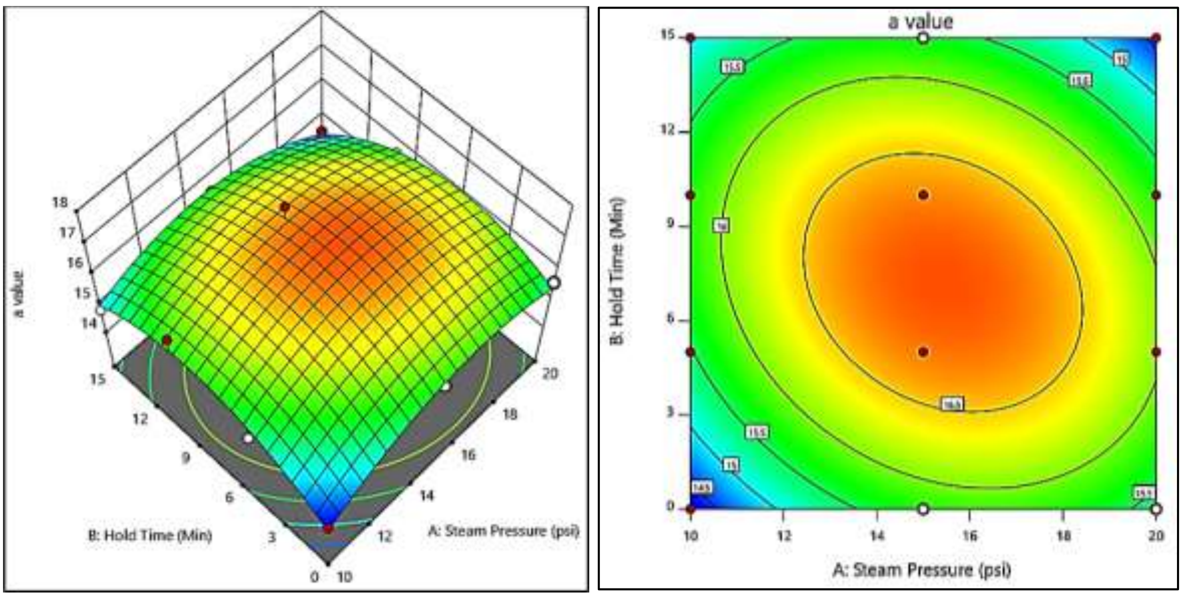

Fig 6: Response surface and contour plots for 'a' value showing the effect of steam pressure and hold time

3.6 Color values (b)

Maximum and minimum intensity of yellowness (b) of 37.33 and 34.60 was observed at steam pressure and holding time of 15 psi and 10 minutes and 10 psi and zero minutes respectively (Table 1). The Model F-value of 10.40 implied the model was significant. The Predicted R^2 (0.61) was in reasonable agreement with the Adjusted R^2 (0.81) (Table 2). The variation of b value with steam pressure and holding time is graphically represented in 3-D surface plots and contour plots (Fig 7). The positive coefficient of model term of A indicated that b value increased with increase in steam pressure, whereas negative coefficients of first order model term of B, interaction term and quadratic terms indicated that it decreased with increase in these variables.

The predicted model for b value can be described by the following equation in terms of coded factors:

$$b\ value = 36.9396 + 0.4075 * A + -0.342 * B + -0.804 * AB + -1.5975 * A^2 + -0.25125 * B^2$$

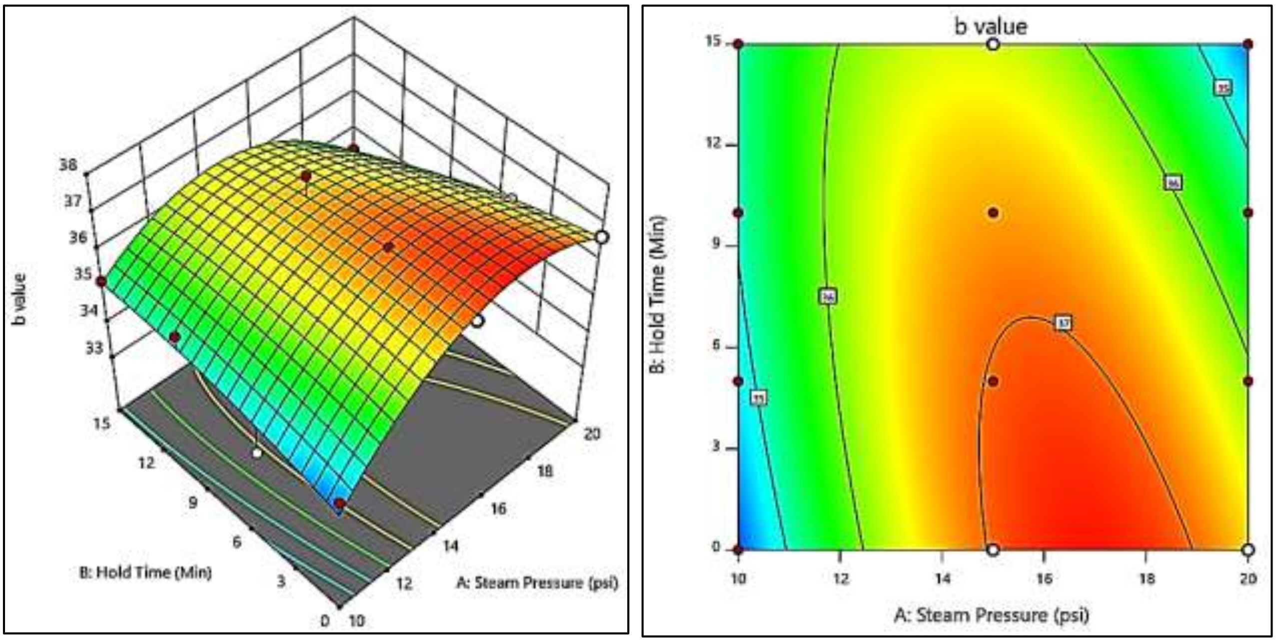

Fig 7: Response surface and contour plots for ‘b’ value showing the effect of steam pressure and hold time

It was concluded from the observations made that there was a significant decrease in desirable color characteristics of luminosity (L), intensity of redness (a) and intensity of yellowness (b) when samples were dried after inadequate boiling or boiling beyond a certain threshold limit This may be attributed to decreased uniformity and poor pigment distribution in turmeric treated inadequately or beyond the optimum range of process parameters. Similar findings were also reported by Bambirra *et al.* (2002) [5].

3.7 Volatile oil (%)

Maximum volatile oil content of 7.05 per cent was recorded when turmeric rhizomes were treated at 10 psi steam pressure for zero minute holding time and lowest volatile oil (5.47 per cent) was obtained with 20 psi steam pressure and 15 minutes holding time(Table 1). The Model F-value of 60.01 implied the model was significant. The Predicted R^2 (0.88) was in reasonable agreement with the Adjusted R^2 (0.96) and Adeq precision of 23.89 was found (Table 2). The variation of the volatile oil (%) with steam pressure and holding time is graphically represented in 3-D surface plots and contour plots (Fig 8). The model terms of A, B, AB and B^2 were significant at 5% level of significance. The negative coefficients of model terms of A, B, AB and B^2 indicated that volatile oil content decreased with increase in these variables, however the zero value of coefficient of second order model term of A^2 indicated that it had no influence on volatile oil content. The model term of A^2 was also not significant at a 5 per cent level of significance.

The predicted model for volatile oil (%) can be described by the following equation in terms of coded factors:

$$Volatile\ oil\ (\%) = 6.55063 + -0.235 * A + -0.5255 * B + -0.1245 * AB + 4.19087e\text{-}16 * A^2 + -0.185625 * B^2$$

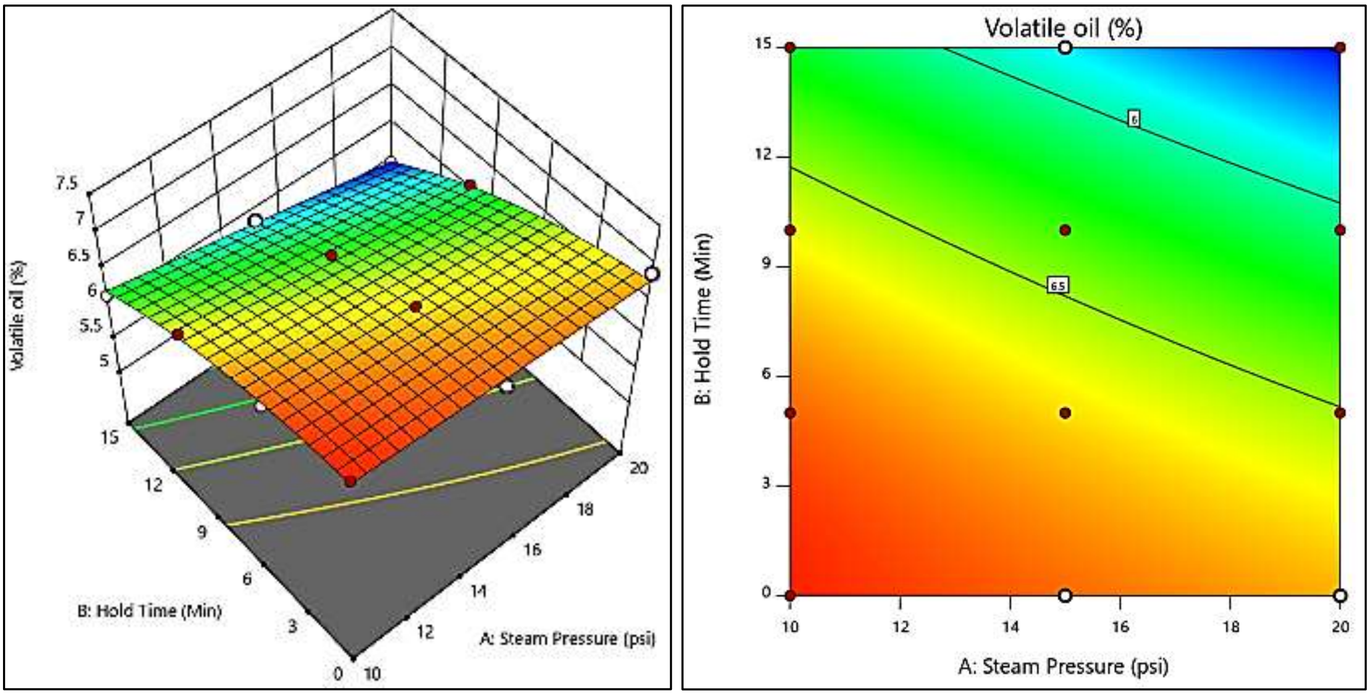

Fig 8: Response surface and contour plots for volatile (%) showing the effect of steam pressure and hold time

3.8 Curcumin content (%)

Highest curcumin content of 4.13 per cent was observed at steam pressure and holding time of 15 psi and zero minutes and the lowest curcumin content of 2.18 per cent was recorded during boiling at 20 psi steam pressure and 15 minutes holding time (Table 1). Model F-value of 22.01 implied that the model was significant. The value of R^2 was 0.95. The Predicted R^2 (0.74) was in reasonable agreement with the Adjusted R^2 (0.91) (Table 2). The variation of the curcumin content (%) with steam pressure and holding time is graphically represented in 3-D surface plots and contour plots (Fig 9). The negative coefficients of first order model terms of A and B indicated that curcumin content (%) decreased with increase in these variables. The interaction term (AB) and second order term of B^2 had a positive coefficient, indicating that curcumin content was proportional to these variables; however the coefficient of second order term of A was negative.

The predicted model for curcumin (%) can be described by the following equation in terms of coded factors:

Curcumin content (%) = $3.64687 + -0.10375 * A + -0.5945 * B + 0.08775 * AB + -0.86375 * A^2 + 0.050625 * B^2$

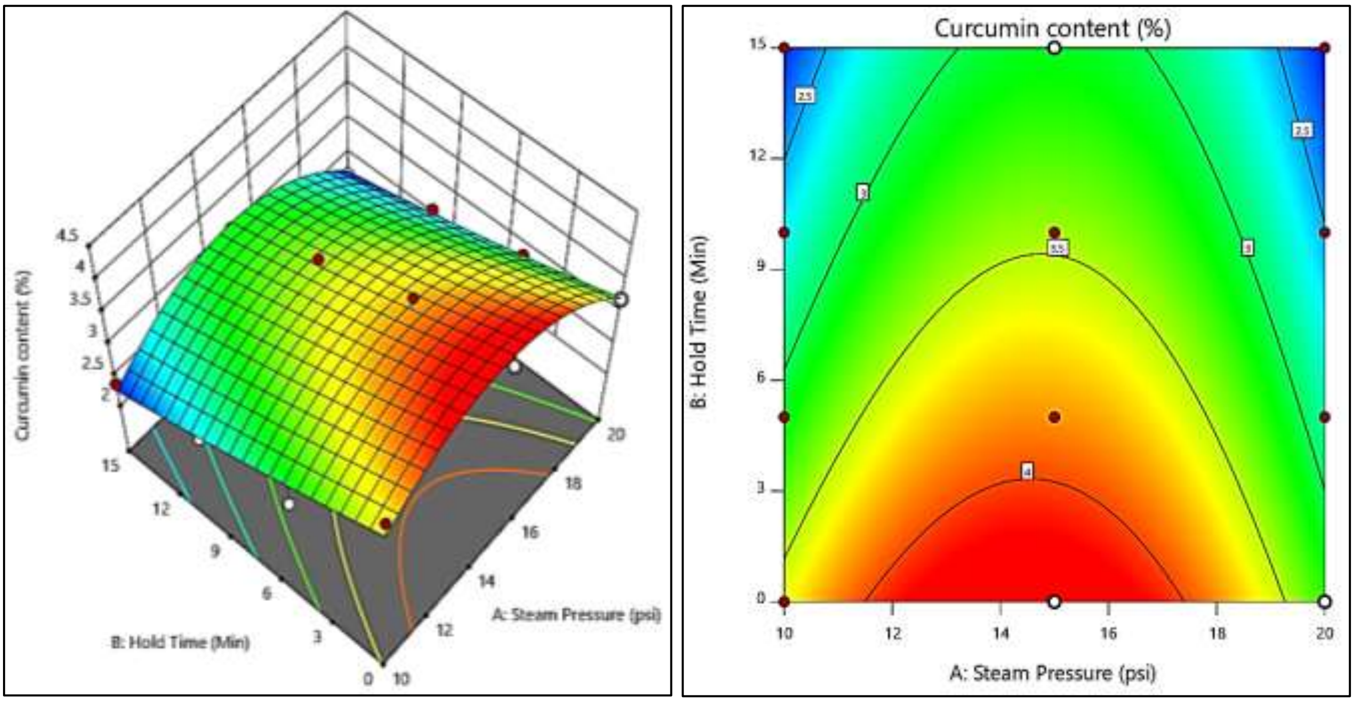

Fig 9: Response surface and contour plots for curcumin content (%) showing the steam pressure and hold time

3.9 Oleoresin content (%)

Highest oleoresin of 15.53 per cent was recorded at 15 psi steam pressure and zero minutes holding time (Table 1). The lowest oleoresin of 10.88% content was recorded when turmeric was exposed to 20 psi steam pressure for 15 minutes holding time. The Model F-value of 23.25 implied the model was significant. The variation of the oleoresin content (%) with steam pressure and holding time is graphically represented in

3-D surface plots and contour plots (Fig 10). The value of R^2 was 0.95. The Predicted R^2 (0.81) was in reasonable agreement with the Adjusted R^2 (0.91) and Adeq precision of 14.91 was found (Table 2). The coefficients of model terms of A, B, AB and A^2 were negative, implying that oleoresin content decreased with increase in these variables, however the quadratic term of B^2 had a positive coefficient.

The predicted model for curcumin (%) can be described by the following equation in terms of coded factors:

Oleoresin content (%) = 13.2379 + -0.59375 * A + -1.506 * B + -0.03075 * AB + -0.38875 * A^2 + 0.20625 * B^2

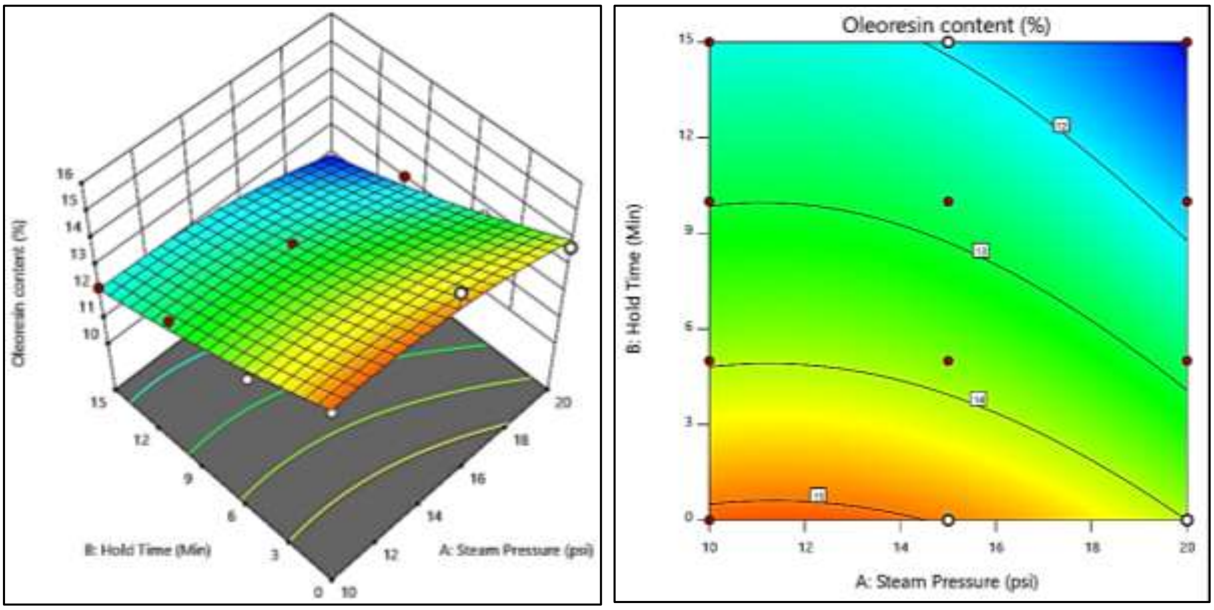

Fig 10: Response surface and contour plots for oleoresin content (%) showing the effect of boiling parameters

3.10 Optimized boiling parameters

Optimization of the process parameters devised a solution with desirability of 0.788 per cent. It was predicted that a combination of steam pressure of 15.93 psi and holding time of 1.08 minutes will result in minimum possible polishing and grinding loss (5.93% and 3.66% respectively) while obtaining the maximum possible final recovery (20.84%), volatile oil (6.84%), curcumin content (4.13%), oleoresin content (14.56%) and maximum possible values of color characteristics (L, a and b). Graphical optimization is represented in the overlay plot (Fig 11)

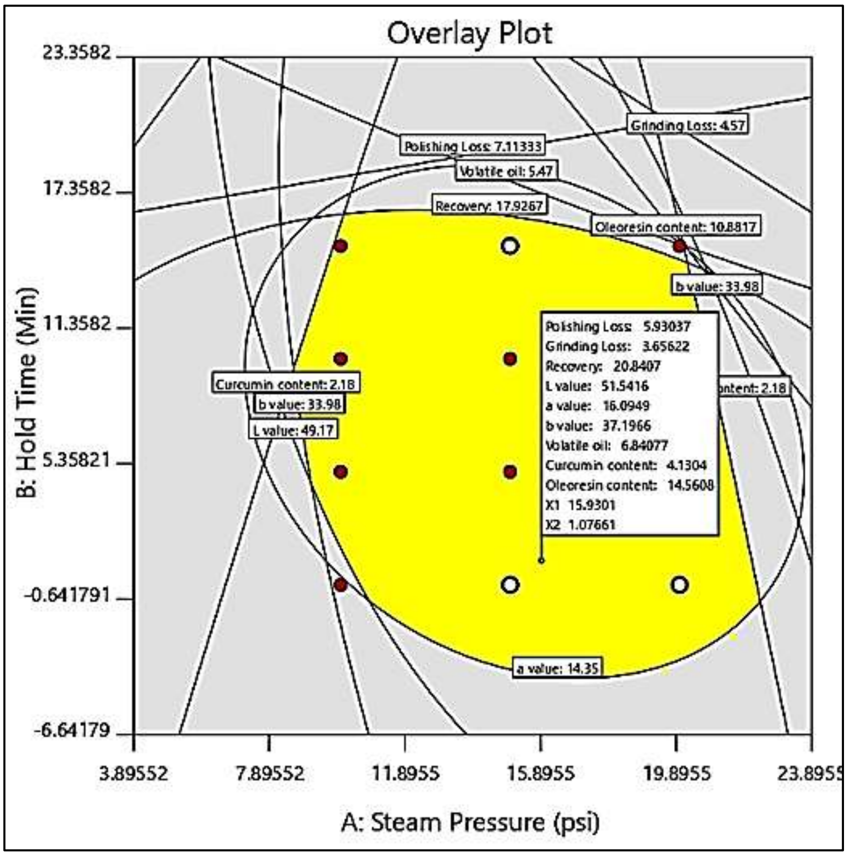

Fig 11: Overlay plot representing graphical optimization

3.11 Testing of developed turmeric boiling system

The developed turmeric boiling system was tested at the optimized set of process parameters i.e. steam pressure of 16 psi and hold time of 1 minute and 6 seconds (1.10 min). Observations on polishing loss (%), grinding loss(%), final recovery(%), L value, a value, b value, volatile oil (%), curcumin content (%) and oleoresin content(%) were made. The results obtained were as expected and in agreement with predicted response values (Table 3)

Table 3: Predicted solutions and actual observations obtained from boiling system

Response	Observed value	Predicted value
Polishing Loss (%)	5.84	5.93
Grinding Loss (%)	3.82	3.66
Recovery (%)	19.44	20.84
L value	53.65	51.54
a value	15.42	16.10
b value	38.34	37.20
Volatile oil (%)	6.39	6.84
Curcumin content (%)	4.18	4.13
Oleoresin content (%)	13.99	14.56

4. Conclusions

The 150 kg turmeric holding pressure vessel system developed for turmeric boiling was successfully tested at optimized boiling conditions. It was observed that steam boiling completed the boiling process sooner as compared to conventional boiling. It was also observed that 30kg of firewood was enough to complete processing of one batch of rhizomes. The product obtained from the developed system had the lowest polishing and grinding loss (5.84% & 3.82%), maximum recovery (19.44%) and turmeric powder with best color characteristics (L=53.65, a=15.42, b= 38.34) and maximum volatile oil, curcumin content and oleoresin content (6.39%, 4.18% & 13.99%) respectively

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