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Optimization of the Ohmic Heating Parameters for Pasteurization of Mango Pulp using Response Surface Methodology

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The present investigation optimized the ohmic heating variables influencing the quality parameters of mango pulp during pasteurization. Three independent variables such as voltage gradients (10–20 V/cm) of ohmic heating, pulp temperature (60–80°C) and pulp concentration (6–14 °Brix) were experimented using Box-Behnken experimental design of response surface methodology. The models generated for the quality parameters as responses such as ascorbic acid, total phenol content, overall acceptability, mold load and bacterial load were tested for their validity using ANOVA. The optimum conditions for pasteurization of mango pulp through ohmic heating were found to be 19.5 V/cm, 75°C and 9.96 °Brix respectively for voltage gradient, pulp temperature and pulp concentration. The values of corresponding quality parameters of ascorbic acid content, total phenolics content, overall acceptability, yeast/mold load and bacterial load were estimated to be 129.39 mg/100g dm, 288.006 mg GAE/100 g dm, 7.40, 11.01 cfu/ml and 162.299 cfu/ml respectively. The results were experimentally verified within a deviation of ±0.5%. Structural variations and functional compounds of fresh, conventionally heated and ohmic heated samples at optimum conditions were analyzed through SEM and FTIR respectively. The ohmic heated sample was found superior over conventionally heated sample with maximum retention of quality parameters. Further, the rheological analysis depicted the closeness of ohmic heated (optimum) sample with the fresh sample.

Key words: Ascorbic acid, Overall acceptability, Pulp concentration, Pulp temperature, Voltage gradient

Introduction

Fruits and vegetables are rich in health contributing essential ingredients for promotion of good health. But because of their short shelf-life due to their high moisture content, they often get wasted, if not preserved appropriately. Despite the dietary and nutrition guidelines in most countries, the consumption of fruits and vegetables in daily diet plans was below the substantial level.[1] Fruits and vegetables can be included in our diet in terms of juices, fortified or fermented beverages and smoothies. These are the refreshing drinks and can contribute in healthy diet plans.[2] Benton and Young[3] suggested to store fruits and vegetables in the form of juices. Thermal preservation methods were cost effective and increased the shelf life of the product by deactivating the enzymes.[4] Thermal treatment methods were also successfully applied to fruit juices as reported by Jiménez-Sánchez *et al*.[5] However, some drawbacks have been noticed in thermal processing methods. Negative impact on antioxidant properties was found in vegetables when compared with raw samples.[6] The efficiency of thermal treatment methods might have been affected due to degradation of quality parameters of the fruit juice[7] and pine apple cubes.[8] Thermal processing techniques are widely used in food industry, which inhibits the growth of microbes. But the process adversely affected the organoleptic properties of the food.[9] Jayachandran *et al*.[10] has shown maximum loss of nutritional components in conventionally processed at 95°C for 10 min, blended beverage of coconut, lemon, and litchi.

Thereafter, some advanced thermal techniques and non-thermal techniques were introduced in the food sector. These technologies have some positive aspects such as reduced capital cost, high energy efficiency

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and less treatment time.[11,12] Recently, ohmic heating has gained the interest of researchers towards it due to the superior quality of finished food products.[13] Ohmic heating is basically considered as the thermal technology due to high heat which helps in inactivation of microorganisms but also have non-thermal effect at lower frequency.[14] Ohmic heating is very productive in liquid foods especially in fruit juices.[15,16] Bhat *et al.*[17] recommended ohmic heating to be encouraged as an alternative to the conventional thermal processes for bottle gourd juice. Application of ohmic heating has a high potential in liquid food industries.[18] So, studies were focused on the replacement of conventional heating by ohmic heating because nutritional components were the priority.[19,20]

Mango (*Mangifera indica*) is a seasonal fruit, popular for its colour, flavour, and taste. Mango fruit as well as its peel are rich sources of ascorbic acid, carotenoids, total phenols and antioxidant properties.[21] Among all the varieties of mangoes, *Totapuri cv.* mango production is high in India because of its high pulp content. This pulp is a good source of phytochemicals and antioxidant properties.[22] The productivity of any processed food product depends on the status of its nutritional components. It should also be safe on the aspects of presence of microbes. As per the study conducted by Santhirasegaram *et al.*[23], complete destruction of microbes was found when mango juice was subjected to high-temperature short-time processing (90°C for 1 min). However, detrimental effects on the overall quality parameters were observed. Similar findings were reported by Tribst *et al.*[24] in mango nectar. Thermal processing of mango puree was an alternative to enhance the shelf life but high temperature reduced the quality parameters as examined by Makroo *et al.*[25] Hence, to overcome the above demerits ohmic heating was introduced. Dima *et al.*[26] reported no loss of flavor compounds in blended juice of carrot, pumpkin, celery, and orange after the ohmic treatment (17.5 V/cm at 70°C, treatment time of 3 to 4 min). Ohmic heating was found to be the best alternative to conventional heating for the inactivation of enzymes in mango pulp.[27] Considering these studies, the present investigation was planned to optimize the process parameters of ohmic heating for pasteurization of mango pulp.

Material and Methods

Standards and Reagents

L- ascorbic acid standard, 2, 6- Dichlorophenol-Indophenol dye, HPO_3 were the chemicals basically used for ascorbic acid estimation. Folin-Ciocalteau reagent, sodium carbonate, $AlCl_3$, 2,2-Diphenyl-1-Pieryl Hydrazyl (DPPH), 2,4,6-tri (2-pyridyl)-s-triazine (TPTZ) solution were some of the chemicals used for other quality parameters analysis. Analytical grade of chemicals and reagents were used for all the analyses.

Sample Preparation and Pre-treatment of Mango Pulp

Matured and ripe mangoes of uniform weight of *Totapuri* variety were collected from the nearby farm of Sambalpur University for the current study. Mangoes were kept under running tap water to remove the dirt and foreign particles. The mango pulp was extracted using a pulper. The mangoes were cut into pieces and subjected to pulping. Peel and stone were collected through separate outlets. The pulp was then homogenized and strained through a filter (0.025 inch).

Ohmic Heating (OH)

The pulp so obtained (18 °Brix) was diluted and was adjusted to different concentration (6, 10 and 14 °Brix). The pulp of specific concentration was subjected to voltage gradient (VG) till the desirable temperature in the design was achieved which was shown in Table 1. Similarly, 15 numbers of ohmic heated samples were prepared as per Box-Behnken design of input variables. Then the treated pulps were subjected to quality analysis for comparison.

Quality Analysis

Phytochemical Analysis

The ohmic heated samples were verified for their phytochemicals and the values were compared with those of fresh sample. Ascorbic acid (AA) was determined by 2, 6-Dichlorophenol- Indophenol visual titration method.[28] Total phenol content was estimated through the modified Folin-Ciocalteau method.[29]

Sensory Analysis

Treated and fresh samples were evaluated for sensory/organoleptic properties such as color, flavor and taste in order to assess the impact of ohmic heating on above attributes. The sensory evaluation was carried out by using 9-point hedonic scale and 10 semi-trained panelists assessed the sensory parameters.[30,31] Overall acceptability was calculated using composite scoring in which weightage factor for each attribute was considered in calculation.

Determination of Total Yeast/Mold Count

Yeast/mold count was determined by AOAC.[32] Potato dextrose agar was used as the media for the

Table1 — Experimental observations of output variables for Box-Behnken matrix

ED	CODED VALUES			UNCODED VALUES			Ascorbic acid content (mg/100g dm)	Total phenol content (mg GAE/ 100g dm)	Overall acceptability	Yeast/Mold load (cfu/ml)	Bacterial load (cfu/ml)
	X_1	X_2	X_3	VG	PT	PC					
1.	−1	−1	0	10	60	10	109.00	292.03	7.14	21	320.00
2.	1	−1	0	20	60	10	**138.49**	**296.76**	7.48	13	202.00
3.	−1	1	0	10	80	10	105.44	279.76	6.80	13	178.00
4.	1	1	0	20	80	10	112.00	281.61	7.14	**11**	**142.00**
5.	−1	0	−1	10	70	6	100.88	270.45	6.58	18	260.00
6.	1	0	−1	20	70	6	116.37	275.86	7.24	14	212.00
7.	−1	0	1	10	70	14	108.45	278.29	7.06	16	236.00
8.	1	0	1	20	70	14	131.89	276.80	7.14	15	221.00
9.	0	−1	−1	15	60	6	107.26	281.69	6.90	**25**	**362.00**
10.	0	1	−1	15	80	6	**99.55**	267.56	**6.50**	16	248.00
11.	0	−1	1	15	60	14	120.76	276.61	**7.86**	20	280.00
12.	0	1	1	15	80	14	109.45	**262.31**	6.92	14	202.00
13.	0	0	0	15	70	10	133.00	290.00	7.64	15	218.00
14.	0	0	0	15	70	10	135.90	292.39	7.80	14	208.00
15.	0	0	0	15	70	10	137.23	294.00	7.50	14	224.00

*ED: Experimental Design, VG: Voltage gradient, PT: Pulp temperature, PC: Pulp concentration; dm:dry matter; GAE: Gallic acid equivalent; cfu: Colony forming units

yeast/mold count. Serial dilution method was used for the determination of yeast/mold load as cfu/ml. The process was repeated thrice.

Determination of Total Bacterial Count

Total plate count method was determined according to the method described by Carielo *et al.*[33] as expressed in Eq. 1. Serial dilution method reduced the concentration of bacterial load by a specific amount. Nutrient liquid agar media was prepared for the bacterial culture in a sterile environment. Three replications were made for each experiment.

Bacterial count (cfu/ml) = Average colony count × Dilution factor × Plating factor … (1)

Fourier Transform Infrared Spectroscopy (FTIR) Analysis

FTIR spectroscopy identifies and analyses the functional properties of materials. The mango pulp samples were analyzed using Perkin-Elmer spectrum-100 model having wave number in a range of 4000–400 cm^{-1}. Origin software was used for the peak determination of polysaccharide unit between 900–1400 cm^{-1}.[34]

Scanning Electron Microscopy (SEM) Analysis

SEM is a process which scans a sample with the help of electron beams to produce magnified images for analysis. This analysis is very effective to find out the structural properties of the material. Dried mango pulp thickness of 40 µm was taken for microscopy analysis using a model SEM EVO MA 15, Carl Zeiss, Germany.[27]

Rheological Analysis

The dynamic flow behaviour of mango pulp at 25°C was characterized by a rotational modular rheometer (Mars III, Thermo fisher scientific, Germany). About 1.5 ml of mango pulp of different concentration (6, 10 and 14 °Brix) was placed separately in between the parallel plate geometry and measurements were made. All the flow measurements were carried out in triplicate.[35]

Statistical Analysis

MINITAB Inc. USA, trial version software was used for the statistical analysis. Response surface methodology is appropriate for optimization and is a combination of statistical and mathematical procedure. The Box- Behnken Design (BBD) of response surface methodology was used which is based on three factor and three level input variables (Voltage Gradient (VG), Pulp Temperature (PT) and Pulp Concentration (PC)). Total number of experimental combinations was 15 for which the quality analysis was carried out.

The uncoded values of the design matrix were shown in Table 1. The four dependent variables were considered as responses (Ascorbic acid content (mg/100g dm), total phenol content (mg GAE/100g dm), overall acceptability, yeast/mold load (cfu/ml) and bacterial load (cfu/ml)). The number of experiments (N) required for the development of BBD was calculated from N = 2k (k−1) + Co, where k is a number of factors and Co is the number of central points. Thus, the experiment was conducted by using 15 experimental runs. Response surfaces were also plotted using valid models generated from statistical analysis at a level of significance of 5%.

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_1^2 + \beta_5X_2^2 + \beta_6X_3^2 + \beta_7X_1X_2 + \beta_8X_2X_3 + \beta_9X_3X_1 \text{ (Y: AA, TPC, OA, ML, BL)} \quad \dots (2)$$

From the above observations the statistical analysis was carried out individually for each response variable from where response functions were developed. Second order polynomial models were fitted to the data of all responses using multiple regression technique. The significance of regression coefficients were analyzed through least square method. The analyzed data were observed and input variables were optimized for best outputs.

In Eq. 2, the regression coefficients were noted as β0, $\beta_1 \ldots \beta_9$ and X_1, X_2, X_3 are independent variables, (VG, PT and PC), Y is mentioned as dependent variable. The adequacy of the model was tested considering R^2 (the coefficient of multiple determination), adjusted R^2, Ficher's F-test and lack of fit. The fitted models were then used to interpret the effect of input parameters on response. The statistical significance of the terms in the regression equation was examined by analysis of variance (ANOVA).

Results and Discussion

The experimental observations recorded for all the five responses corresponding to each experimental run consisting of a set of input variables (VG, PT and PC) are shown in the form of both coded and uncoded values (Table 1). The maximum and minimum values of ascorbic acid content, total phenolics content, overall acceptability, yeast/mold load and bacterial load were 138.49 mg/100g dm, 99.55 mg/100g dm; 296.76 mg GAE/ 100 g dm, 262.31 mg GAE/100g dm; 7.86, 6.50; 25 cfu/ml, 11 cfu/ml and 362.00 cfu/ml, 142.00 cfu/ml which corresponded to experimental run no 2, 10; 2, 12; 11, 10; 9, 4 and 9, 4.

Regression Modeling for Pasteurization of Ohmic Heated Mango Pulp

The regression coefficients along with the R^2, adj R^2 and lack of fit values were presented in Table 2. The efficacy of the models for ascorbic acid content, total phenol content, overall acceptability, yeast/mold load and bacterial load were confirmed by the R^2 values which were higher than 0.9 (0.990, 0.963, 0.906, 0.939 and 0.934 respectively). The corresponding adj R^2 values were 0.974, 0.895, 0.736, 0.830 and 0.815 which were closer to R^2 values.

Table 2 — Significance of regression coefficients of second order model for different responses

Predictors	Coefficients	Ascorbic acid content (mg/100g dm)	Total phenol content (mg GAE/100g dm)	Overall acceptability	Yeast/Mold load (cfu/ml)	Bacterial load (cfu/ml)
Intercept						
	β_0	−730.954*	8.6172	−11.3138	177.125*	2217.53*
Linear						
VG	β_1	17.307*	2.9025	0.4360**	−1.150	−10.100
PT	β_2	18.332*	5.0568**	0.3352**	−3.167*	−37.530**
PC	β_3	19.010*	21.4931*	0.8604*	−5.667*	−75.210*
Quadratic						
VG*VG	β_4	−0.280*	−0.0257	−0.0109**	−0.057	−0.940
PT*PT	β_5	−0.121*	−0.0395**	−0.0023**	0.016	0.170
PC*PC	β_6	−0.874*	−1.0087*	−0.0230*	0.177*	2.440*
Interaction						
VG*PT	β_7	−0.115*	−0.0144	0.0000	0.030	0.410
VG*PC	β_8	0.099	−0.0863	−0.0073	0.038	0.410
PT*PC	β_9	−0.023	−0.0011	−0.0034	0.019	0.230
R-sq		0.990	0.963	0.906	0.939	0.934
AdjR-sq		0.974	0.895	0.736	0.830	0.815
Std error		2.263	3.30945	0.212116	1.51107	23.556

*($p < 0.05$ Significant at 5% level), ** ($p < 0.1$ Significant at 1% level); Adj: Adjusted; VG: Voltage gradient, PT: Pulp temperature, PC: Pulp concentration; dm:dry matter; GAE: Gallic acid equivalent; cfu: Colony forming units

Therefore, it was inferred that the number of variables chosen for experiment was sufficient.

From Table 2 it was revealed that ascorbic acid was highly significant ($p < 0.05$) with respect to the linear as well as quadratic term of all the input variables. The interaction of voltage gradient and pulp temperature and pulp temperature and pulp concentration had negative influence ($p < 0.05$) on ascorbic acid content. On the contrary, total phenol content was significantly affected by both linear and quadratic level of PC at $p < 0.05$. Overall acceptability was computed from the weighted average of different sensory attributes (colour, flavor, and taste). It seemed to have been strongly influenced by the PC at both linear and quadratic terms ($p < 0.05$). However, both yeast/mold load and bacterial load was found to be inversely proportional to both PT and PC which might be due to high heat content with increasing temperature and dehydration of microbes with osmotic effect.

As regards to the total affect, the linear and quadratic effect was significant at $p < 0.05$ for all the responses except bacterial load. However, the total interactive influence of input variables on ascorbic acid was prominently visible at significant level 10% (Table 3).

Optimization of Process Parameters for Pasteurization of Mango Pulp

The aim of the present investigation was to optimize the process variables of ohmic heating of mango pulp in order to maximize the phytonutrients such as ascorbic acid content, total phenol content and sensory score for overall acceptability while minimizing the yeast/mold load and bacterial load. Since the responses were five in numbers, individual optimization of responses could not match with the values for each other. Therefore, multiple optimization technique was adopted. In order to have a set of common process parameters a compromise was made on the maximum/minimum response values using the desirability function. Therefore, a set of target values with lower and upper limits were selected. Using this range of response values of acceptability, a set of compromised optimum condition was estimated with individual as well as composite desirability. Fig. 1 displayed all these values and exhibited graphically how the responses varied with the change in input variables. The optimum conditions for VG, PT and PC were found to be 19.49 V/cm, 75°C and 9.96 °Brix respectively. With these optimum conditions, the responses such as ascorbic acid content, total phenol content, overall acceptability, yeast/mold load and bacterial load were predicted to be 129.39 mg/100g dm, 288.006 mg GAE/100g dm, 7.40, 11.01 cfu/ml and 162.299 cfu/ml respectively with an overall desirability of 0.949. The optimum input conditions along with corresponding response and desirability values were shown in Fig. 1. Park *et al.*[36] found in ohmic heated apple juice of 8 °Brix, 60 V/cm for 20s was sufficient to achieve 5-log reduction without compromising the product quality, whereas in ohmic heated papaya pulp, the optimal condition for improving the pasteurization process were 13.33 V/cm with a retention time of 2 min.[35] Similar observations have also been observed by previous researchers.[27] inferred OH to be an effective technology to inactivate PPO at moderate pasteurization conditions (72°C, 15 s), with minimal modifications on the physicochemical properties of Ataulfo mango pulp. Application of VG of 17 V/cm and treated at 90°C for 1 min was found to be best for anola pulp[37] with respect to vitamin C and bacterial load.

Table 3 — Analysis of variance of input variables and their effect responses

Parameters	DF	Ascorbic acid content (mg/100g dm)		Total phenol content (mg GAE/100g dm)		Overall acceptability		Yeast/Mold load (cfu/ml)		Bacterial load (cfu/ml)	
Source		SS	F	SS	F	SS	F	SS	F	SS	F
Regression	9	2699.29	58.55*	1409.24	14.30*	2.16143	5.34*	175.517	8.54	93330.0	7.88*
Linear	3	1273.90	58.65*	403.98	10.92*	1.14930	5.62*	114.25**	5.22	27846.8	3.48
Square	3	1274.90	82.96*	991.27	30.17*	0.85513	6.34*	47.767	6.97*	9206.0	5.53*
Interaction	3	150.49	9.79*	13.98	0.43	0.157	1.16	13.5	1.97	2277.3	1.37
Residual	5	25.61		54.76		0.22497		11.417		2774.4	
Lack of fit	3	16.26	1.16	46.66	3.84	0.17990	2.66	10.75	10.75	2643.7	13.49
Pure error	2	9.36		8.10		0.04507		0.667		130.7	
Total	14	2724.90		1464.00		2.38640		186.933		42104.4	

*($p < 0.05$ Significant at 5% level), ** ($p < 0.1$ Significant at 1% level);; SS: Sum of squares; dm: dry matter

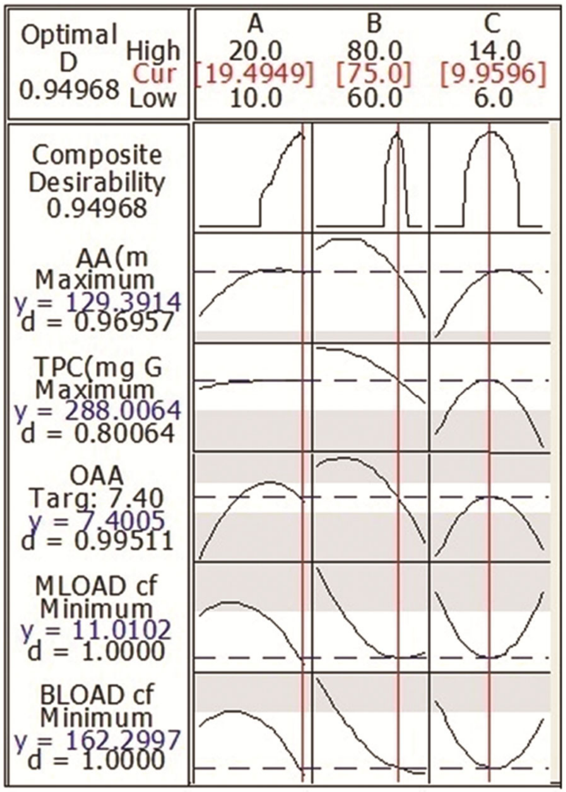

Fig. 1 — System generated optimization plot showing input and output variable

Effect of Input Variables on the Response Surface

The surface profiles for different responses were drawn as a function of two variables with 3rd one constant at optimum and were depicted in Figs 2–6. The figures described the dependence of responses on the input variables. From Fig. 2 (a, b and c) it is clear that with increase in temperature the ascorbic acid content decreased but it increased with increase in VG and PC. Since ascorbic acid content is heat sensitive it decreased with increasing temperature. Mango pulp with higher concentration contained higher amount of ascorbic acid component. The trend of above result was also observed by Thangalakshmi *et al.*[38] for sapota juice. Total phenolics content of mango pulp followed a similar pattern as that of ascorbic acid content. No significant change in total phenol content was observed with VG (Fig. 3 a, b and c). Variation of overall acceptability with change in input variables was illustrated in Fig. 4 a, b and c. The score increased slowly up to certain level of all the input variables within the experimental zone and then decreased towards higher range of all the three input variables. The mold and bacterial load decreased with increase in pulp temperature and voltage gradient which is due to the obvious reason of pasteurization effect (Fig. 5 a, b and c; Fig. 6 a, b and c). However,

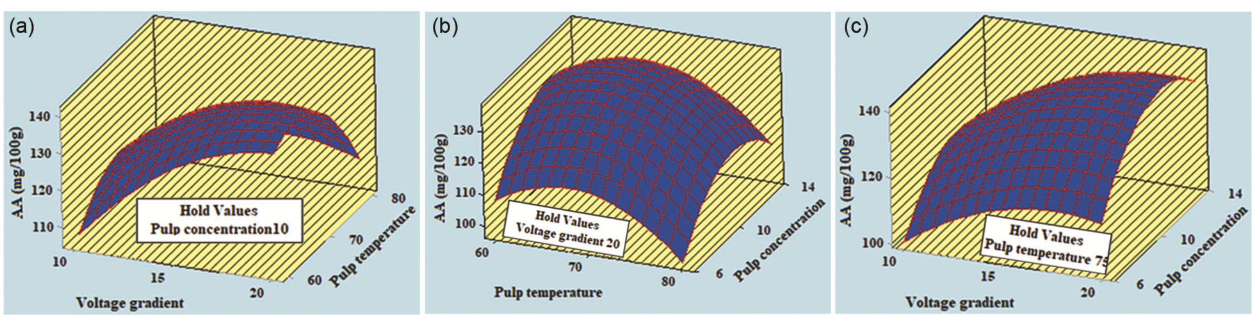

Fig. 2 — Surface plots for ascorbic acid (a) voltage gradient vs pulp temperature (b) pulp temperature vs pulp concentration (c) voltage gradient vs pulp concentration

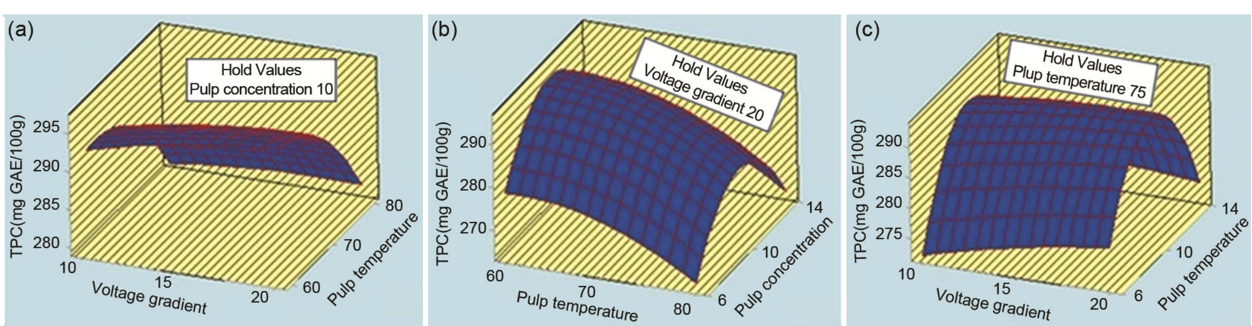

Fig. 3 — Surface plots for total phenolics content (a) voltage gradient vs pulp temperature (b) pulp temperature vs pulp concentration (c) voltage gradient vs pulp concentration

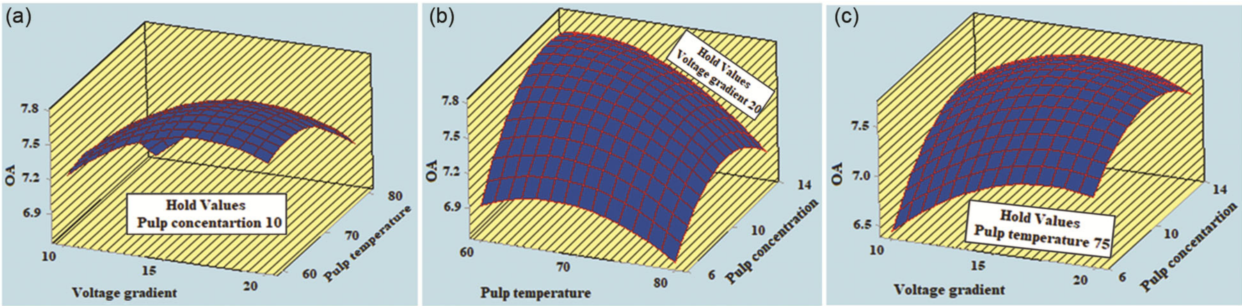

Fig. 4 — Surface plots for overall acceptability (a) voltage gradient vs pulp temperature (b) pulp temperature vs pulp concentration (c) voltage gradient vs pulp concentration

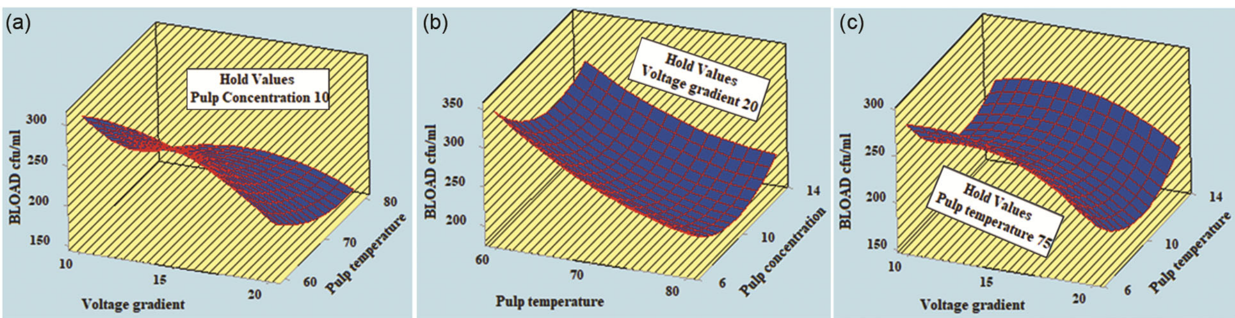

Fig. 5 — Surface plots for total yeast/ mold load (a) voltage gradient vs pulp temperature (b) pulp temperature vs pulp concentration (c) voltage gradient vs pulp concentration

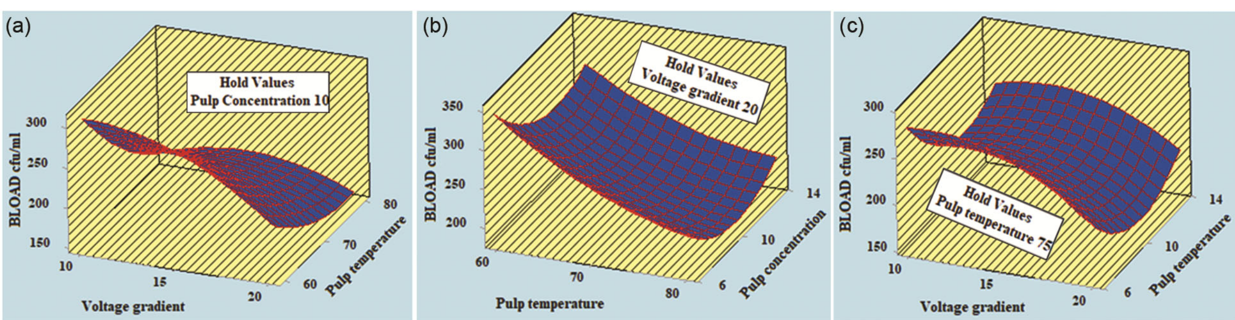

Fig. 6 — Surface plots for total bacterial load (a) voltage gradient vs pulp temperature (b) pulp temperature vs pulp concentration (c) voltage gradient vs pulp concentration

the microbes load varied quadratically with pulp concentration.

Effect of Ohmic and Conventional Heating on Functional Properties of Mango Pulp

FTIR spectroscopy of raw mango pulp, conventionally heated at (90°C) and ohmic heated optimum condition for (20 V/cm, 75°C, 10 °Brix) are represented in Table (Supplementary Table-S1 a, b and c) and Fig. 7 (a, b and c) to determine the different important functional groups present in juice. The broad absorption area 3200–3500 cm^{-1} is corresponding to OH stretching is present in raw and both the treated sample. The peak in the range of 2000–2200 cm^{-1} is attributed to C–H stretching and N= N = N stretching groups. Moreover, the peak at 1638 cm^{-1} is assigned to amide I groups could be seen in all the three samples. The peaks linking 1000–1200 cm^{-1} are corresponded to glycosidic linkage between sugar units.[39] Interestingly, the 'finger print' regions of polysaccharide unit are found in the range between 900–1400 cm^{-1}. It was clearly visible in untreated juice and ohmic heating samples. This was confirmed the presence of glucose, sucrose and fructose, respectively. In the conventional treatment, the finger print region was not shown because during the treatment, the sugar units might be reduced.

Table S1 — FTIR analysis of (a) fresh mango pulp (b) conventionally heated mango pulp and (c) ohmic heated mango pulp

(a)

Wave Number (cm^{-1})	Functional groups	Compound class	Appearance
3306.21	O-H Stretching	Alcohol	Strong, Broad
2112.08	C-H Stretching	Alkyne	Medium, Broad
1638.93	C=O Stretching	Primary Amide	Strong, Sharp
1419.49	O-H Stretching	Alcohol	Medium
1261.16	C-O Stretching	Aromatic Ester	Week
1106.29	C-O Stretching	Easter	Week
1055.30	S=O Stretching	Sulfoxide	Medium
998.04	C=C Bending	Alkene	Week

(b)

Wave Number (cm^{-1})	Functional groups	Compound class	Appearance
3316.61	O-H Stretching	Alcohol	Strong, Broad
2108.00	C-H Stretching	Alkyne	Medium, Broad
1635.57	C=O Stretching	Primary Amide	Strong, Sharp
1057.58	S=O Stretching	Sulfoxide	Medium
990.94	C=C Bending	Alkene	Week

(c)

Wave Number (cm^{-1})	Functional groups	Compound class	Appearance
3273.01	O-H Stretching	Alcohol	Strong, Broad
2162.70	N=N=N Stretching	Azide	Medium, Broad
2115.33	C-H Stretching	Alkyne	Medium, Broad
1638.64	C=O Stretching	Primary Amide	Strong, Sharp
1425.22	O-H Stretching	Alcohol	Medium
1055.44	S=O Stretching	Sulfoxide	Medium
997.10	C=C Bending	Alkene	Week

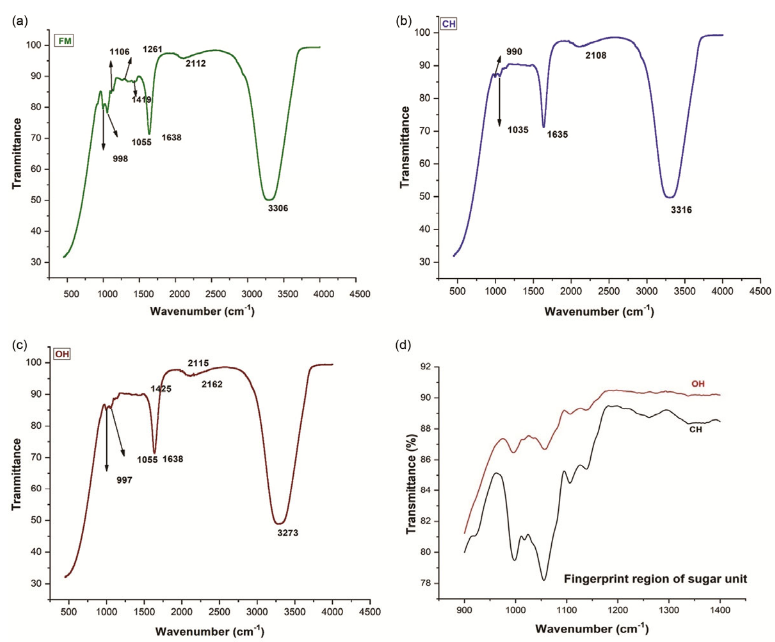

Fig.7 — FTIR spectrum for (a) fresh mango pulp (b) conventionally heated mango pulp and (c) ohmic heated mango pulp and (d) Finger print region of sugar unit of both raw and ohmic heating treated juice

Hence, ohmic heating treatment is better option for the thermal process which maintains the juice quality and safety (Fig. 7 d). On the contrary, the conventionally treated sample was devoid of sugar units (finger print region). During the treatment the sample might have lost their sugar unit. It was reported that, the changes of intensity and absorption peaks of a molecule can be credited to the difference in their structural and

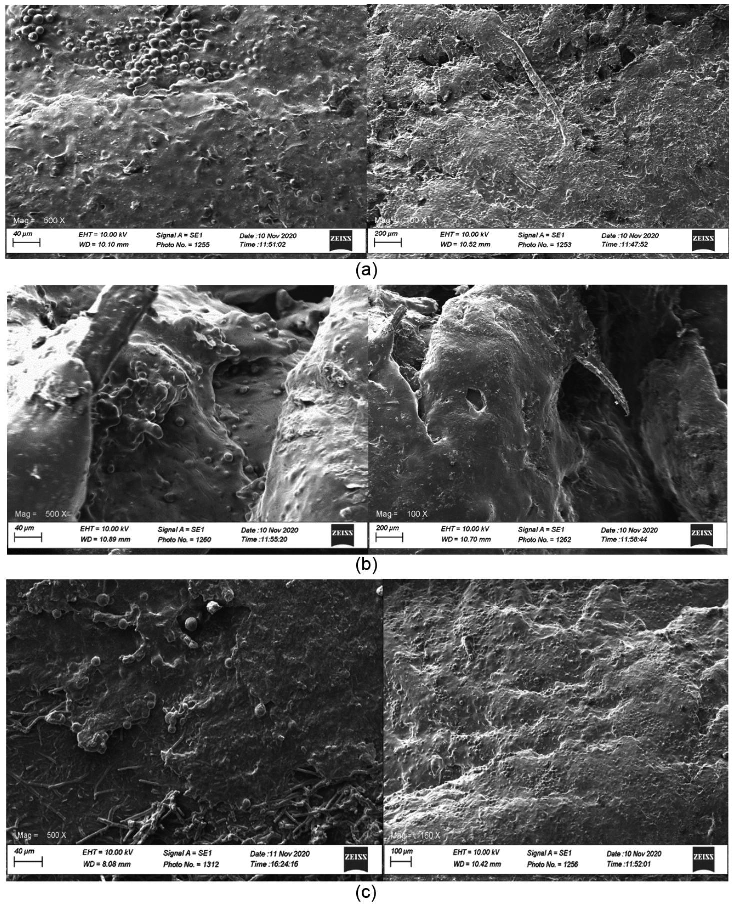

Fig. 8 — Scanning electron micrographs (SEM) analysis (a) fresh mango pulp (500x and 100x) (b) conventionally heated mango pulp (500x and 100x) and (c) ohmic heated mango pulp (500x and 100x)

functional composition.[40] Thus, it is probable that the entire sample with similar type of spectrum (or smaller spectral variation) have same structure and composition, which was observed in the present work. Overall results suggested that, ohmic heating is the better option of thermal process which could maintain most of the functional groups as that of fresh pulp.

Effect of Conventional and Ohmic Heating on Structural Properties of Mango Pulp

The scanning electron micrographs of fresh mango pulp, conventionally and ohmic heated mango pulp at 500X and 100X is shown in Fig. 8 (a to c). The fresh pulp images exhibited spherical globules and fiber particles in bulk. Both conventional and ohmic heated samples showed physical changes due to thermal treatment. In case of conventional heated samples severe breakdown of particles were observed in both the magnified images. There were large cracks and cervices indicating discontinuity of the molecular components. On the contrary, the ohmic heated samples at 100X image exhibited very uniform structure with spherical globules and prominent fibers network distribution which is attributed to the swelling of the fibers. This ultimately leads to the increase in soluble fiber which increased the organoleptic attributes. This fact supports the analytical results obtained in the present investigation. The SEM images further support the phenomenon of uneven heating in conventionally heated sample and volumetric heating in ohmic heated pulp.[27]

Rheological Analysis of Ohmic Heated Mango Pulp

The rheological behaviour of ohmic heated mango pulp (optimum condition, 20 V/cm, 75°C and 10 °Brix) samples along with the untreated fresh pulp (10 °Brix) have been exhibited in Fig. 9. Flow characteristics of mango pulp showed pseudoplastic non-Newtonian behavior with the presence of yield stress in both the pulp. However, the ohmic heated pulp had higher range of shear stress of 27 to 60 pascal than fresh pulp with 22 to 42 pascal within

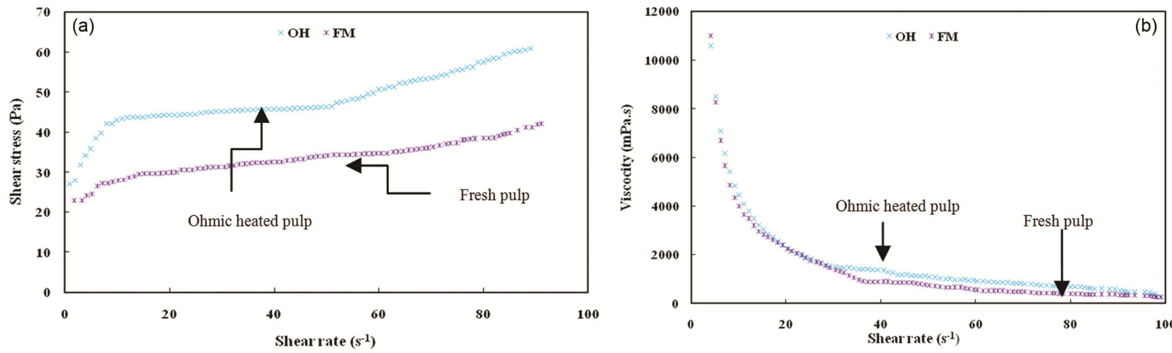

Fig. 9 — Rheological behavior for both ohmic heated and fresh mango pulp (a) shear stress-shear rate curve (b) viscosity as a function of shear rate

stress rate of 100 s^{-1}. At higher values of shear rate, the difference in shear stress among the samples was slightly more (Fig. 9 a). Fig. 9 b illustrated the resemblance of ohmic heated pulp with fresh pulp in terms of variation of viscosity with shear rate. The viscosity values of both the pulp were almost same about 11,000 mPa. s. Viscosity of both the pulp declined very closely and attained about 275 and 250 mPa. s by ohmic heated and fresh mango pulp respectively. Since ohmic heating is very fast and heated for a short period of time, there was no structural change and there was no alteration in the texture. Gomathy *et al.*[35] showed papaya pulp to follow non-Newtonian and pseudoplastic behavior with yield stress. The study established the similarity of ohmic heated pulp to that of the fresh pulp without any structural breakdown upon ohmic treatment.

Conclusions

The current research revealed that the ohmic heating can be an option to substitute the conventional method used for pasteurization. The study analysed in details on the effect of ohmic heating and pulp characteristics on its sensory properties, bioactive compound levels and microbial inactivation. The results have been summarized through mathematical equations and surface plots in order to have a better flexibility in the selection of operating range. The optimum conditions of input variables for pasteurization of mango pulp was found to be 20 V/cm, 75°C and 10 °Brix respectively for voltage gradient, pulp temperature and pulp concentration.

In order to obtain ascorbic acid and total phenol content as 129.39 mg/100 g and 288.006 mg GAE/100 g with overall acceptability score of 7.40. The microbial load was also within the safe limits. FTIR and SEM analysis indicated ohmic heated mango pulp samples to be superior to conventionally heated samples with maximum quality retention as those of fresh mango pulp. The research finding would contribute towards the preservation of mango pulp with better retention of the quality components.

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