Journal of Engineering Science and Technology
Vol. 6, No. 2 (2011) 228 - 239

ENHANCEMENT OF JUICE RECOVERY FROM CARROT USING 2-STAGE PRESSING WITH OHMIC HEATING

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Abstract

Experiments were conducted to study the enhancement of carrot juice recovery using 2-stage pressing with ohmic heating. The study was designed using Response Surface Methodology employing the Box-Behnken design. The independent variables were: duration of first pressing (1, 2, 3 min.), voltage gradient (15, 20, 25 V/cm) and final temperature (60, 70, 80ºC). Control experiments, without any ohmic heating between the 2-stage pressing, were also conducted for the purpose of comparison. Total juice recovery and juice quality were the dependent variables. Mathematical analysis for multistage pressing was applied to 2-stage expression process. The total juice recovery increased with increase in the duration of 1st pressing. Maximum enhancement in juice recovery in 2-stage expression with ohmic heating over control was 13.76%. The total solids ranged between 7.55 to 11.12% and increased with increase in the duration of 1st pressing. Total soluble solids were in the range of 3.6 to 6.6°Brix and increased at lower voltage gradient and higher final temperature. The ohmic heating did not cause much change in the colour of juice. The study indicated that maximum juice recovery of 98.9% can be obtained with 1st pressing of 2.72 min., ohmic heating up to a final temperature of 65.6°C under a voltage gradient of 15 V/cm followed by 2nd pressing of 10 min.

Keywords: Carrot juice, Ohmic heating, 2-stage juice expression, Juice quality, Response surface methodology.

1. Introduction

Vegetable and fruit juices are rich in vitamins and minerals, which play a special role in the nutritional requirements, particularly in case of infants and elderly people. The fruit juice industry, all over in the world is emerging as a major agro-based food industry. It also has potential in beverage industry.

Nomenclatures

a^*	Redness colour parameter
b^*	Yellowness colour parameter
J	Juice expression, %
j	Dry basis juice content, fraction
L^*	Lightness colour parameter
p	Probability
R	Total juice recovery, %
R^2	Coefficient of determination
TS	Total solids
TSS	Total soluble solids
t	Time, s
W	Weight, g

Greek Symbols

β_w	B-carotene content, mg/100g wet basis
ΔE	Total colour difference, NBS units

Subscripts

i	Initial pulp conditions
k	Stage of pressing
I	First pressing
II	Second pressing

Abbreviations

ANOVA	Analysis of variance
NBS	National bureau of standards

Carrot juice is gaining popularity due to its comparatively lower cost than other fruit juices and high nutritive value. It contains the vitamins A, B, C, D, E, and K; the minerals calcium, phosphorous, potassium, sodium, and traces of other minerals; and a trace amount of protein. It is rich in vitamin A and carotene content (8.2-11.4 mg/100 g carrot). Carrot juice has a number of health benefits. Drinking carrot juice is thought to be extremely beneficial for the liver due to Vitamin A's cleansing effects. Vitamin A reduces bile and fat in the liver. Carrot juice has anti-carcinogenic properties. Vitamin E contained in carrot juice helps to prevent cancer. Carrot juice helps in relieving constipation and bowel movement problems.

The juice from fruits and vegetables is commonly extracted by mechanical pressing, also called expression. The juice yield from expression process can be increased using various pre-treatments, i.e., crushing, pulping, hydrothermal treatment, enzymatic treatment, etc., Sharma et al. (2006) have used Response Surface Methodology (RSM) to optimize pretreatment conditions of carrots to maximize juice recovery [1]. In some cases, multi-stage pressing is also practiced to increase juice recovery from fruits and vegetables.

Ohmic heating is a novel process wherein electric current is passed through foods or other materials with the primary purpose of heating them due to internal energy generation within the material [2]. Ohmic heating is now regarded as highly attractive commercial technique for food processing. A large number of potential future applications exist for ohmic heating, including its use in blanching, evaporation, dehydration, fermentation and extraction, etc.

It has been observed that ohmic heating improves juice recovery in case of juice expression from fruits and vegetables. Lima and Sastry [3] observed that ohmic pretreatment of fruit and vegetable samples increased juice yields over raw samples or those pretreated with conventional or microwave heating. Ohmic heating increased juice yield and required less input work, compared to microwave heating. In another study the best efficiency of juice extraction from pressing was observed when the potato and apple tissues were treated electrically at a temperature of 50°C. Such mild heat processing combined with electrical treatment considerably increased juice yield when mechanically pressed [4]. Wang and Sastry [5] studied the effect of moderate electro-thermal treatments on juice yield from cellular tissues. They employed ohmic and microwave heating to investigate electro-thermal effects on apple juice yield by preheating apple samples to 40 or 50°C. Their results showed that apple juice yield was strongly improved by both thermal pretreatments. The effect of ohmic pretreatment on juice yield increased with the pretreatment temperature.

In this the effect of ohmic heating and 2-stage pressing was studied with a view to enhance juice recovery from carrot.

2. Materials and Methods

Experiments were designed and conducted to study the enhancement of carrot juice recovery using 2-stage pressing with ohmic heating. In these experiments, first the carrot pulp was pressed and juice was expressed, the residual cake was subjected to ohmic heating under different conditions and again pressed for further juice expression. The total juice recovery in the 2-stage pressing was calculated.

Fresh, tender carrots of commercial variety were used in this study. Carrots were peeled, cut into 2-3 length wise pieces and shredded in an electrically operated shredder. The shreds were ground in a grinder to make a uniform pulp. The first pressing was done on a number of 100 g pulp samples for the required time. The cake samples so obtained after first pressing were crushed and mixed together for ohmic heating. 125 g of the cake was transferred to the ohmic heating device. It was compressed to the sample height of 5 cm in ohmic heater to overcome the problem of poor electrical contact. The cake was heated at different voltage gradients to different final temperatures. The heated cake was allowed to cool to about 40°C before the second pressing. The second pressing was done on 100 g of sample for 10 min.

All the pressings were done at 0.5 Ton (19.4 kg/cm^2) in a test cylinder with the help of a laboratory hydraulic press (Model: M-25) made by FREDS CARVER INC. USA. For ohmic heating, the setup developed by Patil [6] was used. The ohmic heating, device employed a rectangular geometry and consisted of two rectangular electrodes made of stainless steel placed on a rectangular plate of Perspex sheet. The dimensions of stainless steel electrodes were 5×12 cm and thickness of 0.1 cm. The distance between the two electrodes was 6 cm.

The experiments were designed using Response Surface Methodology (RSM) as per the Box Behnken design [7]. Box–Behnken designs are experimental designs in which each independent variable is placed at one of the three equi-spaced values. Box-Behnken designs provide statistically sufficient information for the use of Response Surface Methodology with reduced the number of experimental combinations. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. RSM explores the relationships between several explanatory variables and one or more response variables using a quadratic model having the following form:

$$Y = a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3 + a_{11} X_1^2 + a_{22} X_2^2 + a_{33} X_3^2{}_2 \\ + a_{12} X_1 X + a_{13} X_1 X_3 + a_{23} X_2 X_3 \qquad (1)$$

where, a's are regression coefficients

X_1, X_2, and X_3 are independent variables in coded form.

Y is response

The duration of first pressing, voltage gradient and final temperature attained during ohmic heating were taken as the independent variables. Three levels of each factor, i.e., duration of first pressing (1, 2, 3 min.), voltage gradient (15, 20, 25 V/cm) and final temperature (60, 70, 80°C) were considered. The total juice recovery, juice expression kinetics, heating behavior, total solids, total soluble solids and colour of juice, were taken as the dependent variables. The coded and real values of the independent variables are tabulated in Table 1 and the experimental design is summarized in Table 2.

Table 1. Coded and Real Values of Independent Variables for Box-Behnken Design.

Independent Variables	**Coded Levels**		
	-1	**0**	**1**
X_1=Time of first pressing (min.)	1	2	3
X_2=Voltage gradient (V/cm)	15	20	25
X_3=Temperature (°C)	60	70	80

Table 2. Box-Behnken Design of Experiments.

Exp. No.	**Coded levels**			**Real values**			**Exp. No.**	**Coded levels**			**Real values**		
	X_1	X_2	X_3	X_1	X_2	X_3		X_1	X_2	X_3	X_1	X_2	X_3
1	0	1	-1	20	25	60	10	1	-1	0	3	15	70
2	0	1	1	2	25	80	11	-1	1	0	1	25	70
3	0	-1	-1	2	15	60	12	-1	-1	0	1	15	70
4	0	-1	1	2	15	80	13	0	0	0	2	20	70
5	1	0	-1	3	20	60	14	0	0	0	2	20	70
6	1	0	1	3	20	80	15	0	0	0	2	20	70
7	-1	0	-1	1	20	60	16	0	0	0	2	20	70
8	-1	0	1	1	20	80	17	0	0	0	2	20	70
9	1	1	0	3	25	70							

Moisture content was determined by oven drying approximately 5 g of sample was dried at 100°C in a hot air oven for 18 hours [8]. Colour was determined using photographs of freshly prepared carrot juice and the L^*, a^* and b^*' values were obtained using Adobe Photoshop software [9]. Total solids in the carrot juice were determined by AOAC method [10]. The hand refractometer (0-32

°Brix) was used in measuring the total soluble solids of juice at 20°C [8]. The carotene content of each sample was estimated by the method of Goodwin [11].

3. Results and Discussion

Total juice recovery in 2-stage expression, juice quality and optimization of total juice recovery is discussed in the following sections:

3.1. Mathematical analysis of multi-stage juice expression

Since the basis for computation of juice expression, J, is different in 1st and 2nd pressing (different cake weight with different moisture contents) these juice expressions can not be simply added to give total juice expression of two stages. In a multistage process the juice expression needs to be defined based on the dry mass of the cake, which shall range between 0 and initial juice content in the pulp, j_i.

Let, m_i = moisture content of initial pulp (wet basis)
j_i = moisture content of initial pulp (dry basis)
W_{ji} = weight of juice in initial pulp
W_k = weight of cake taken for k^{th} stage
W_{dk} = dry mass in the cake taken for k^{th} stage
ΔW_{jk} = weight of juice expressed in k^{th} stage
m_k = moisture content in cake before k^{th} stage
J_k = juice expression in k^{th} stage (%, w.b.)

Now,

$$J_k = \frac{\Delta W_{jk}}{W_k} \times 100 \tag{2}$$

The % juice recovery, R, of a given stage, k, can be defined as juice expressed in k^{th} stage, specified as percent of the juice available in initial pulp, that is

$$R_k = \frac{\Delta W_{jk}}{W_{ji}} \times 100$$

Dividing numerator and denominator by W_{dk},

$$R_k = \frac{\Delta W_{jk} / W_{dk}}{W_{ji} / W_{dk}} \times 100$$

Since

$$W_{dk} = W_k(1 - m_k) \tag{3}$$

$$R_k = \frac{\Delta W_{jk} / W_k(1 - m_k)}{j_i} \times 100$$

$$R_k = \frac{J_k}{j_i(1 - m_k)} \tag{4}$$

Total juice recovery in N stages

$$R = \sum_{k=1}^{N} R_k \tag{5}$$

In 2-stage pressing system:

For 1^{st} pressing:

$$R_I = \frac{J_I}{j_i(1-m_i)} \tag{6}$$

Since

$$j_i = \frac{m_i}{1-m_i}$$

$$R_I = \frac{J_I}{\frac{m_i}{1-m_i} \times (1-m_i)}$$

$$R_I = \frac{J_I}{m_i} \tag{7}$$

For 2nd pressing:

$$R_{II} = \frac{J_{II}}{j_i(1-m_2)} \tag{8}$$

The total juice recovery, R, in 2-stage pressing is

$$R = R_{\text{I}} + R_{\text{II}} \tag{9}$$

3.2. Total juice recovery in 2-stage expression

For 1^{st} pressing alone, the juice recoveries for t_I=1, 2 and 3 min. were 45.89, 62.29 and 71.64% respectively. The corresponding juice recovery in 2-stage expression without ohmic heating (Table 3) were 73.16%, 84.36% and 86.23%, for t_I=1, 2 and 3 min. respectively. The total juice recovery in 2-stage expression with ohmic heating ranged between 77.11 to 100% (probably a bit of rounding error).

The incremental recovery with ohmic heating over control, ΔR, lies in the range of -4.3 to +13.76%. In four cases ΔR was negative, possibly indicating a process degradation due to ohmic heating. In other 13 cases, ohmic heating caused an improvement over the control. In any case the results (R as well as ΔR) indicate a very promising role of ohmic heating in improving juice recovery in 2-stage expression.

The total juice recovery, R, and incremental recovery, ΔR, were analyzed using Design-Expert software. Multiple linear regression analysis was used to fit the data as a second order response surface, Eq. (1). In testing the statistical significance of the model, its terms and lack of fit, 95% confidence interval ($p < 0.05$) was used.

The following model (R^2=0.8715) was obtained for total juice recovery

$$R = 94.14 + 4.8X_1 - 2.26X_2 + 0.15X_3 - 6.43X_1^2 - 1.2X_2^2 - 5.61X_3^2 - 3.46X_1X_2 - 2.19X_1X_3 + 3.55X_2X_3 \tag{10}$$

The model was significant at 5% level (p = 0.0401) and the lack of fit was insignificant, indicating that the model is adequate. The ANOVA of the total juice recovery shows that effect of X_1 (1st pressing time) was significant ($p = 0.0141$) at linear level. There was no interaction between the variables that could affect the total juice recovery. At quadratic level, X_1 (first pressing time) and X_3 (final temperature) showed the significant effect ($p = 0.0176$) and ($p = 0.03$) respectively. The coefficient of 1st pressing time at linear level was positive; therefore with larger duration of 1st pressing the juice recovery was more.

Similar RSM analysis was attempted for ΔR also, it was observed that the model did not fit significantly ($p = 0.1604$, $R^2 = 0.7759$). Therefore the model was discarded and the 2-stage expression process was analysed in terms of total juice recovery using Eq. (10).

Table 3. Total Juice Recovery and Quality Parameters of the Expressed Juice.

Coded values			R_1	R_2	R	ΔR	TS (%)	TSS	Colour			ΔE
X_1	X_2	X_3	(%)	(%)	(%)	(%)		(°Brix)	L^*	a^*	b^*	
Means of 1st pressing							**7.12**	**3.16**	**48.67**	**37.75**	**38.75**	-
-1	#	#	45.89	27.27	73.16	#	7.75	3.88	51.25	11.00	50.25	29.23
0	#	#	62.29	22.07	84.36	#	7.22	3.02	58.50	10.50	54.75	33.10
1	#	#	71.64	14.60	86.23	#	6.29	2.76	62.25	1.50	48.00	39.80
0	1	-1	62.29	19.15	81.45	-2.91	11.12	3.60	60.75	9.25	37.00	31.01
0	1	1	62.29	25.97	88.26	3.90	8.20	5.26	64.00	5.00	39.50	36.17
0	-1	-1	62.29	31.22	93.51	9.15	7.85	4.86	62.74	4.00	41.25	36.65
0	-1	1	62.29	23.83	86.12	1.76	10.84	6.60	72.00	-2.50	58.25	50.45
1	0	-1	71.64	13.83	85.47	-0.77	8.81	4.66	69.25	7.75	57.25	40.82
1	0	1	71.64	10.31	81.95	-4.29	10.73	6.46	74.00	6.25	47.75	41.41
-1	0	-1	45.89	31.96	77.86	4.69	8.25	4.80	53.72	3.29	39.40	34.83
-1	0	1	45.89	37.23	83.12	9.96	8.09	5.66	58.50	1.75	54.10	40.35
1	1	0	71.64	17.36	89.00	2.77	10.92	4.13	66.00	1.75	50.25	41.58
1	-1	0	71.64	28.36	100.00	13.76	8.13	5.26	73.00	-3.75	54.25	50.54
-1	1	0	45.89	34.03	79.93	6.76	7.55	5.40	51.25	-2.5	59.30	45.27
-1	-1	0	45.89	31.22	77.11	3.95	9.95	6.06	60.75	11.00	56.50	34.30
0	0	0	62.29	33.83	96.12	11.76	9.71	5.33	74.50	-5.80	59.25	54.63
0	0	0	62.29	33.04	95.33	10.97	8.63	4.80	61.25	-2.50	49.75	43.58
0	0	0	62.29	17.76	80.06	-4.30	9.48	4.20	65.00	4.75	54.50	40.05
0	0	0	62.29	31.17	93.46	9.10	8.11	4.86	63.50	1.50	48.00	40.24
0	0	0	62.29	29.37	91.66	7.30	7.99	4.86	59.00	5.75	38.00	33.64
Means of 2nd pressing with ohmic heating									**64.07**	**2.65**	**49.66**	**40.91**

Control experiments without ohmic heating (X_2 and X_3 not applicable)

3.3. Analysis of quality of the juice

The quality of the expressed juice was determined in terms of total solids (TS), total soluble solids (TSS), colour and β-carotene.

Total solids (TS) and Total soluble solids (TSS)

For the juice expressed in 1st pressing, mean TS and TSS values were 7.12 and 3.16% respectively. The TS values for juice expressed in 1, 2 and 3 min. pressing were 7.75, 7.22 and 6.29%. The corresponding TSS values were 3.88, 3.02 and 2.76 °Brix. The TS values show that more solid loss takes place initially and then it decreases gradually with further pressing. The TSS was found to decrease gradually with 1st pressing time.

The TS and TSS data are tabulated in Table 3. The TS ranged between 7.55 to 11.12%. TSS values lied in the range of 3.6 to 6.6 °Brix. These responses of TS

and *TSS* were analyzed in the Design-Expert. The following model for total solids was obtained:

$$TS = 8.61 + 0.59X_1 + 0.13X_2 + 0.23X_3 - 2.5\times10^{-3}X_1^2 + 0.53X_2^2 + 0.36X_3^2 \\ + 1.3X_1X_2 + 0.52X_1X_3 - 1.48X_2X_3 \qquad (11)$$

The model was significant at 5% level (p = 0.0238) with R^2=0.8943. The ANOVA of the total solids showed that X_1(time of 1st pressing) has significant (p = 0.0420) effect on *TS* at linear level. The interactions X_1 X_2 (time of 1st pressing and voltage gradient) and X_2 X_3 (voltage gradient and final temperature) were significant (p = 0.0073 and p = 0.0040 respectively.) The coefficient of 1st pressing time indicates that *TS* increased with increase in the time of 1st pressing.

In case of *TSS*, the following model was obtained.

$$TSS = 4.96 - 0.18X_1 - 0.55X_2 + 0.76X_3 + 0.28X_1^2 - 0.032X_2^2 + 0.15X_3^2 \\ - 0.12X_1X_2 + 0.23X_1X_3 - 0.02X_2X_3 \qquad (12)$$

The model was significant at 5% level (p = 0.0477) with R^2= 0.8626. ANOVA of the total soluble solids indicated that the effect of X_2 (voltage gradient) and X_3 (final temperature) was significant at linear level (p = 0.0148 and p = 0.0034 respectively), while there was no effect at interactive and quadratic level. The coefficients of the significant terms indicated that *TSS* increased with decrease in the voltage gradient and increase in the final temperature.

Colour

The colour of the juice obtained after 1st and 2nd pressing was determined in terms of *L**, *a** and *b** values, where *L** is the luminance or lightness component, which ranges from 0 to 100, and *a** (from green to red) and *b** (from blue to yellow) are the two chromatic components, which range from -120 to +120. The values are presented in Table 3. The *L**, *a** and *b** values ranged between 51.25 to 74.5, -5.8 to 11 and 37 to 59.3 respectively. The responses *L**, *a** and *b** were analyzed in Design-Expert. None of these responses models fitted the data well. Therefore the variation of colour (*L**, *a** and *b** values) was analyzed with respect to linear model in operating conditions. It was seen that redness, *a**, and yellowness, *b**, are not influenced by any of the variables, but the lightness, *L**, is significantly influenced by time of 1st pressing (p = 0.0002) and voltage gradient (p = 0.029). Therefore it can be concluded that with ohmic heating the colour composition does not change; only the juice becomes lighter or darker.

The colour was also analyzed on the basis of its deviation from the colour of juice obtained after 1st pressing, ΔE. The total colour difference, ΔE was calculated as in [7]:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad (13)$$

ΔE values for the juice of all the 17 experiments were computed and are presented in Table 3. ANOVA of linear model for ΔE also indicates that the change in colour due to ohmic heating is not significantly influenced by any of the variables and can be represented by an average (40.19 NBS units). The ΔE for controls corresponding to 1, 2 and 3 min. of 1st pressing are 29.23, 33.10 and 39.80 NBS units. The data indicate that, the colour change in control (without ohmic heating) is more as 1st pressing time is increased. With increase in the 1st pressing time, the juice of 2nd pressing becomes lighter (L^* increasing), less red (a^* decreasing), while the yellowness, b^*, remains more or less the same. It can be seen that the average L^*, a^*, b^* and ΔE values are comparable to that of control with t_I = 3 min., confirming that ohmic heating does not cause much change in the colour.

β-carotene

β-carotene was determined in a representative case (center point) and control with t_I = 2 min. The β-carotene in the pulp, cake and juice obtained in 1st and 2nd pressing were determined. The β-carotene in pulp was 8.33 mg/100 g. In case of cake β-carotene values ranged between 4.03 to 6.08 mg/100 g. In case of juice, it lied between 0.12 to 1.46 mg/100 g. It may be noted that β-carotene in juice was much less than in cake.

The juice of 1st pressing had much higher β-carotene (1.46 mg/100 g) than that of 2nd pressing (0.51 mg/100 g for control and 0.12 mg/100 g after ohmic heating). In case of cake the β-carotene content was 6.08 mg/100 g after 1st pressing, 4.72 mg/100 g for 2nd pressing without ohmic heating and 4.02 mg/100 g in juice obtained after ohmic heating. The above values of β-carotene were used to estimate the total β-carotene (cake+juice) in different situations. For 100 g pulp, the total β-carotene in case of 1st pressing and 2nd pressing without ohmic heating were similar (3.53 and 3.49 mg). In case of ohmic heating the total β-carotene was reduced to 2.65 mg indicating a possible destruction of β-carotene as a result of ohmic heating. However this observation is based on very limited data and more comprehensive data is needed for deriving conclusions regarding β-carotene loss.

3.4. Optimization of total juice recovery

The second order model for total juice recovery, Eq. (10) was used to examine the nature of response surface and to optimize the process. Numerical optimization was carried out using Design-Expert 7.0.0 statistical software. The optimum point resulting in the maximum juice recovery was:

$$X_1 = 0.72, \quad X_2 = -1, \quad X_3 = -0.44$$

The contour plots were generated for juice recovery considering two factors at a time and keeping the remaining one at the optimum point. The contour plots are shown in Figs. 1, 2 and 3. It is clear from these figures that the juice recovery was maximum at low levels of voltage gradient. The optimum conditions in terms of the real values were:

Time of 1st Pressing = 2.72 min.
Voltage Gradient = 15 V/cm
Final Temperature = 65.6 °C

The predicted juice recovery at the optima was 98.92%. While there is no experimental data at this point, the juice recovery at the nearest experimental condition (t_I = 3 min.; VG=15 V/cm; T_f = 70ºC) was also highest.

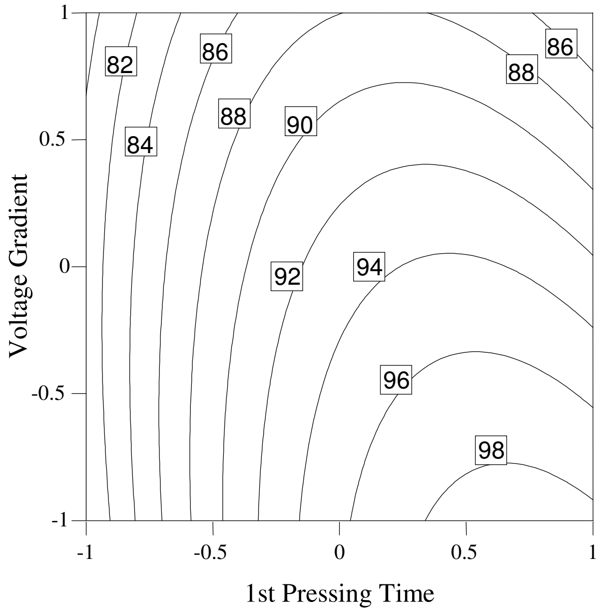

Fig. 1. Contours of Juice Recovery with respect to 1st Pressing Time and Voltage Gradient (at Optimum Point).

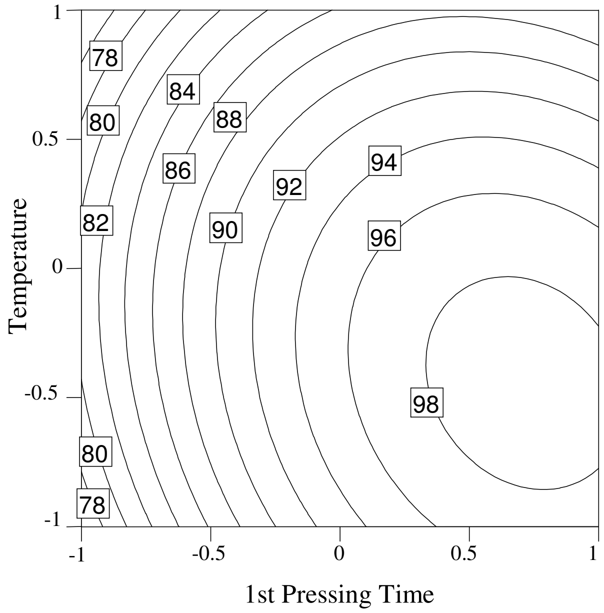

Fig. 2. Contours of Juice Recovery with respect to 1st Pressing Time and Temperature (at Optimum Point).

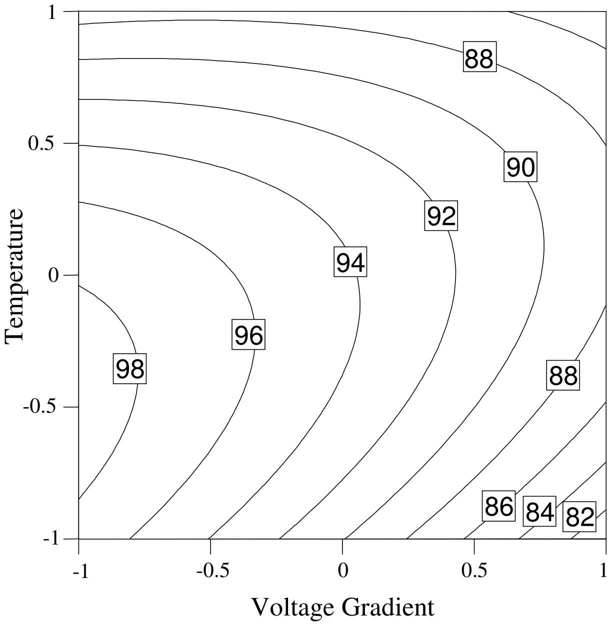

Fig. 3. Contours of Juice Recovery with respect to Voltage Gradient and Temperature (at Optimum Point).

4. Conclusions

Ohmic heating can enhance the juice recovery. The increment in juice recovery with ohmic heating over control was up to 13.76%. The ohmic heating does not cause much change in the colour, but may reduce the β-carotene content. A maximum juice recovery of 98.92% can be obtained with 1st pressing of 2 min. 45 s (2.72 min.) followed by ohmic heating up to a final temperature of 66°C (65.6°C) under a voltage gradient of 15 V/cm and 2nd pressing of 10 min.

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