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Influence of process variables on quality attributes of jaggery prepared by vacuum pan evaporation technology

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ABSTRACT : Jaggery is a solid unrefined, non- centrifugal cane sugar (NCS) with unique colour, flavor and aroma obtained from crushing of cane and evaporating of sugarcane juice. In this paper vacuum pan evaporation method were used sugarcane juice boiling at vacuum pressure (Vp : 500-700 mm of Hg), time (t:60-90 min) and temperature (T:100-120^0 C). The quality attributes of jaggery developed from vacuum pan evaporator were investigated at different process variables. The developed jaggery were analyzed for physiochemical. Results showed that TSS (^{0} Brix) and Hardness (H_d) increased with increase in vacuum pressure and time, whereas moisture content percentage (%) and water activity (a_w) decreased with increase in vacuum pressure and time at variable temperature of 110^0 C. Fuzzy logic method was used to evaluate the sensory characteristic of prepared jaggery.

KEY WORDS : Jaggery, Vacuum pan, Variables, Temperature, Quality

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Jaggery is a complex food with various types of nutritional and bioactive compounds. When compared to refined sugar jaggery has low recognition, with the advent of urbanization, low consumption of jaggery, low colour, unhygienic production and storing facilities, non branding and non-packing of and not availability jaggery in required amounts. Jaggery manufacturing is a typical rural enterprise. (Fabian *et al.,* 2019). It provides jobs to the unemployed rural people in their vinecity with minimum capital investment (Anwar, 1999). Jaggery is named in varied names in different states of India like "Goda" in (Sanskrit) "Gur" in (Urdu) "Gud" in (Hindi), "Bellam" in (Telugu), "Bella" in (Kannada), "Vellam" in (Tamil and Malayalam), "Panela" in (Mexico) and "Hong Tang" in (China).

Sugarcane (*Saccharum officinarum*) is a cash crop and is indigenous to tropical parts and South East Asia. Mainly used for production of sugar, jaggery and ethanol. Worldwide sugarcane occupies a part of 26.52 million ha with a complete production of 172.36 million tones. Today 115 countries of the world cultivate sugarcane for sugar production where as India production is 27.25 million tons of world share. In India the share of the states in production, Uttar Pradesh (1623.35), Maharashtra (726.37), Karnataka (299.02). Tamil Nadu (165.62), and Andhra Pradesh with (79.78) lakh tone. An annual produce of 3550.90 was estimated in the year 2017-18 and total cane crushing and processing industries were 716 (Anonymous, 2020).

Traditionally jaggery preparation involves crushing of cane using three roller horizontal crusher, filtration of juice to remove foreign material like dust, dirt and mud by settling or by using rotary Sieve. Filtration is followed by clarification by adding natural clarificants and lime is added for pH adjustment. Then boiling of juice is done for 3-4 hours or juice attains a temperature of 118ºC by continuous stirring and scum was removed from time to time and boiling is continued till juice attains a temperature 120ºC or until it reaches final sticking point. After boiling the concentrated juice is taken out of fire and is allowed for natural cooling with occasional stirring. After solidification the liquid is cooled and made into granular form or poured into different moulds to get different solid shapes (Jagannadha Rao *et al.,*2007).

Juice boiling is the second most important unit operation in the preparation of jaggery. The main objective of boiling is to concentrate the juice to make thick syrup to form solid or powder form of jaggery. (Kumar and Kumar, 2018) Tradationally various types of boiling systems like open pan with fire hood, open pan steam boiling, and 3 pan furnace boiling were in use by farmers use till date. In this paper vacuum evaporation method was developed to make jaggery.

Vacuum evaporation is that the method of inflicting the pressure in a very liquid stuffed instrument to be reduced below the vapour pressure of liquid, inflicting the liquid to evaporate at a lower temperature than traditional (Foakett, 1951). When the process is applied to jaggery the water is evaporated and removed thus jaggery can be stored for long period of time without spoilage. The vacuum pan evaporation is the most advanced and automated method in terms of saving of boiling time, fuel and labour. It also increases the yield of jaggery and retains the quality parameters of jaggery such as colour, aroma, texture and taste. Keeping the above advantages in view the present study was carried out with design of continuous vacuum pan evaporator and influence of process variables on quality attributes of jaggery prepared from vacuum pan process.

After design and fabrication of type vacuum pan evaporator, performance evaluation was carried out with a view to optimize process variables at various independent parameters *i.e.*, Pressure, Time and Temperatures with corresponding dependent parameters of Brix, Water activity, Color, Hardness, Moisture content, Sucrose content, and Reducing sugars.

■ METHODOLOGY

Raw Material:

The sugarcane (*Sacharam officianarum*) variety is selected from different fields of RARS Anakapalle, ANGRAU farm for experiment.

Methodology of Jaggery Making:

In advanced automated, method the boiling of juice is being done in closed vessel by circulating the vapors generated from evaporator by creating vacuum, removing the vapors and condensing the vapors by using vacuum pump which is ultimately leads to raise of high temperature in short duration consequently leads to obtain high concentrated jaggery as output.

Design layout of the experiment:

Table A : Optimization of variables

Independent Variables	Dependent Variables
Vacuum Pressure (500,550,600,650,700) mm of Hg	Concentration (^{0}Brix)
Time (60,70,80,90,100) min	Water activity
Temperature (100, 105,110, 115, 120) ºC	Color (L*, a* and b*)
	Hardness
	Moisture Content
	Sucrose analysis
	Reducing Sugars

Optimization of process parameters for making jaggery in vacuum pan evaporator:

Design layout (Table A) indicates the various levels at which the trails were carried out. A three variable with three level of each variable with RSM design of BOX Behnken was used to show interaction of Vacuum pressure (Vp), Time (t) and Temperature (T) on physio chemical quality of jaggery.

Statistical analysis and experimental design:

Staggered absolute plan was utilized for the streamlining of procedure parameters for the utilization of jaggery making process by vacuum skillet evaporator. The staggered categoric (general factorial) structure permits scientists to have factors that each have an alternate number of levels. It will make an examination that incorporates every single imaginable mix of your factor levels. The contrast between the factors were tried for criticalness utilizing the single direction ANOVA investigation technique. The measurable programming bundle Design Expert 11.0' was utilized for relapse examination of the information and estimation of relapse condition coefficients. A second-request polynomial condition was utilized to communicate the needy factors (Y) as a component of the autonomous variable.

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_3X_3 + \beta_{11}X_{12} + \beta_{22}X_{22} + \beta X_2 + \beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{23}X_2X_3 + \beta_{24}X_2X_4 + \beta_{14}X_1X_4 + \beta_{34}X_3X_4 \quad .... (1)$$

Determination of physico-chemical parameters of jaggery:

Total soluble solids:

A Digital pocket refractrometer were used for measurement of absolute dissolved solids (TSS) (ATAGO make, Model: PAL-1) after calibration the readings are displayed digitally on screen in ^{0}Brix (Rangana, 1986).

Moisture content:

Dampness substance of all samples was dictated by technique of hot air woven method (AOAC, 1984) and arrived at the midpoint of. The outcomes have been communicated as rate on dry premise.

$$\text{Moisture content, MC \% (db.)} = \frac{(W_1 - W_2)}{W_2} \quad .... (2)$$

Water activity:

The measurement of water activity is the key parameter in the quality control of moisture sensitive products or minerals. If there is too much water in a product, there is a risk of microbial growth and water migration. This can lead to clumping, changes in consistency and reduced shelf life. The water activity of edible coated solid jaggery samples was measured by using HygroLab C1 Bench-Top Indicator, Rotronic AG Bassersdorf, Switzerland. The sample was placed in the a_w probe and the reading showed in the display.

Hardness:

The surface quality of hardness or level of relaxation was estimated by deciding the most extreme infiltration power for put away jaggery tests. A surface analyzer model TA XD in addition to as appeared in the plate was utilized to gauge the hardness as far as power (Newton) required for the entrance of test (P/75) into the example utilizing the accompanying parameters. A round and hollow test of 5mm width was utilized for the infiltration into the examples.

RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Total soluble solids:

The TSS concentration of sugarcane juice varied from 61.8 to 83.2 °Brix (Table 1). The TSS content was highly significant at 1% level of linear terms and 5%

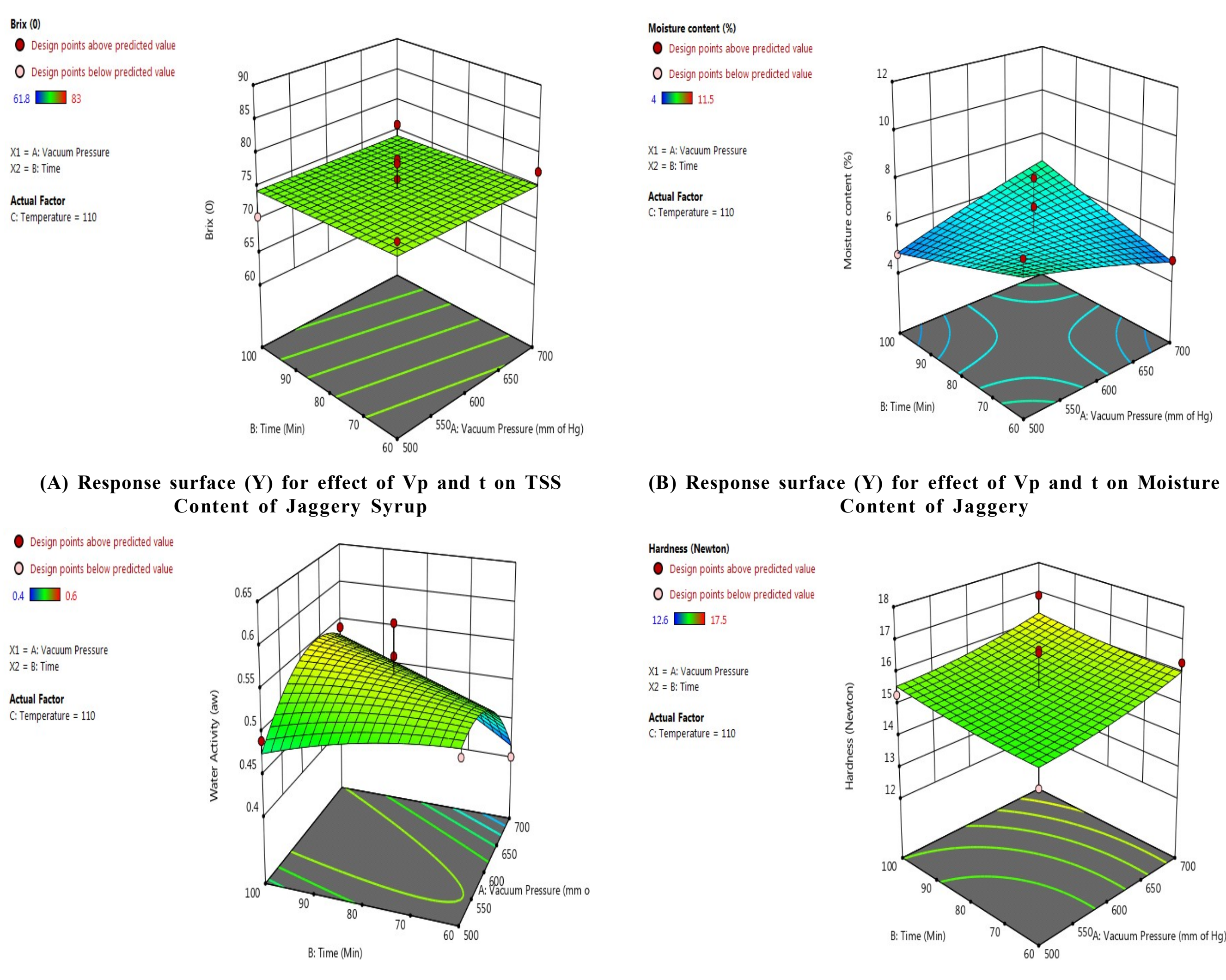
Table 1 : Spread Sheet of different data of various dependent and independent parameters

Std	Run	A : Vacuum pressure (mm of Hg)	B : Time (min)	C : Temperature (^{0}C)	Brix	Moisture content (%)	Water activity (a_w)	Hardness (%)
11	1	600	60	120	63.5	8.2	0.53	14.2
4	2	700	100	110	70.5	4.3	0.42	17.2
7	3	500	80	120	76.2	7.5	0.51	14.6
12	4	600	100	120	61.8	4	0.44	17.1
8	5	700	80	120	80.2	7	0.51	15.2
15	6	600	80	110	83	9.3	0.6	12.6
9	7	600	60	100	78.5	5.9	0.58	16.9
3	8	500	100	110	77.3	5.4	0.48	17.5
13	9	600	80	110	76	10.3	0.61	13.2
1	10	500	60	110	72.2	4.8	0.66	15
2	11	700	60	110	77.5	11.5	0.67	12.9
14	12	600	80	110	65.5	4.8	0.49	15.3
5	13	500	80	100	82.5	10.6	0.6	13.2
16	14	600	80	110	78.5	5	0.5	16.7
17	15	600	80	110	68.6	6.1	0.54	16.9
10	16	600	100	100	79.2	4.5	0.56	16.6
6	17	700	80	100	81.3	4.9	0.4	16.3

level of quadratic terms (Table 2). The relationship developed with coded values of TSS concentration was shown in (Table 3). The positive co-efficients of the 1st order terms of pressure and time indicated that concentration (TSS) increased with increase of these variables. The variation of the TSS with time and vacuum pressure is graphically represented in 3-D surface plots of Fig. 1 (A). Increased in vacuum pressure (Vp) and time (t) leads to an increase in Total soluble solids (TSS) content of sugar juice. The reason behind increase in concentration of TSS upto 83^0 Brix with increase in temperature and pressure may be due to quick vanishing

Sr. No.	Dependent variable	Predictive Model	R^2 value
1.	Concentration	$+76.92 +1.22 A -0.1750 B +5.70 C +0.6750 AB +2.23 AC -1.57 BC -1.10 A^2 +0.2525 B^2 -3.20 C^2$	0.80
2.	Moisture content	$+5.90 -0.0125 A +0.0000 B -2.76 C +0.9750 AB -0.1500 AC -0.1250 BC -0.1000 A^2 +0.0250 B^2 +1.80 C^2$	0.82
3.	Water activity	$+0.5380 -0.0125 A +0.0175 B -0.0725 C +0.0400 AB -0.0100 AC +0.0050 BC -0.0440 A^2 -0.0090 B^2 +0.0160 C^2$	0.84
4.	Hardness	$+15.54 +0.3875 A +0.1625 B +2.10 C -0.0250 AB +0.1000 AC -0.3000 BC+0.1425 A^2 +0.0925 B^2 -0.5825 C^2$	0.85

Where A= Vacuum pressure, B= time and C= Temperature



(A) Response surface (Y) for effect of Vp and t on TSS Content of Jaggery Syrup

(B) Response surface (Y) for effect of Vp and t on Moisture Content of Jaggery

(C) Response surface (Y) for effect of Vp and t on Water Activity of Jaggery

(D) Response surface (Y) for effect of Vp and t on Hardness of Jaggery

Fig. 1 : Response surface plots on effect of TSS, Moisture content, Water activity and Hardness at temperature of 110^0 C

of juice at raised temperature to 105^0 C abandoning just sugars which has high breaking point with lesser volume and profundity of juice in bubbling container.

Maximum value of TSS value (82.5) and minimum value (61.8) were obtained at Vp= 500 and 80 min and Vp =600 and time = 60 min. Jagannadha Rao *et al.* (2009) reported similar results of TSS for sugarcane juice (54.6-81.9), Palmyra juice (46-81) and Date palm (51-81).

Moisture content:

For dependent variable, moisture content of a nonlinear 2nd order regression equation was developed as a function of independent real values for Vp (A), t (B) and Temperature(C) as shown in Table (2). The maximum moisture content (%) = 11.5 per cent and minimum moisture content (%) = 5.4 per cent was observed in Table 1. Loss in moisture content during boiling was effected by p and t on linear terms and t^2 on quadratic terms at 5% level of significance (Table 3). The reason behind the decrease in moisture content in both time and vacuum pressure graph is due to loss of moisture as time proceeds and jaggery turns towards drying with grains becomes separated from each other.

Similar results on moisture content were reported by (Madhava *et al.*, 2015) after performing experiment on Palmyra sap boiling and jaggery samples moisture content was ranged between 4.9 to 7.2% (db).

Water activity:

The variations of water activity (a_w) with different process parameters were graphically shown in 3-D surface plot and statistically proved in (Table 2). Increase in pressure and time leads to decrease in water activity, a_w of jaggery Fig. 1 (C). The created connection with real quantities (Subsequent to non juge terms) has been given in equation (Table 1) with R^2= 0.84. The maximum a_w were observed at Vp= 500, t= 60 min and T= 110^0 C and minimum values were observed at Vp= 700, t= 80 min and T= 100^0 C.

It was found that there was significant difference of a_w among the samples. The experimental data revealed that the water activity of jaggery samples ranges from 0.45 to 0.66. Jaggery samples obtained at higher temperature and time shows less a_w compared to jaggery samples obtained at low temperature. Comparing the a_w values to the moisture levels, it was found that the greater the moisture, the higher the a_w. The same was reported by (Verma and Narain, 1990 and Lava *et al.*, 2017) for solid jaggery in the range of 0.44±0.02 to 0.62 ± 0.02.

Hardness:

Hardness of jaggery samples varies from 12.5 to 17.5 (Table 1). The second order polynomial model

Table 2 : ANNOVA of the second order polynomial of dependent variables (TSS, Moisture content, Water activity and Hardness)

		Total soluble solids (^{0}Brix)			Moisture content (%)			Water activity (a_w)			Hardness (%)		
Source	df	Sum of squares	F value	P value	Sum of squares	F value	P value	Sum of squares	F value	P value	Sum of squares	F value	P value
Model	9	353.53	3.18	0.0708	78.71	3.79	0.0465	0.0621	4.38	0.0323	38.60	4.67	0.0273
A-Vacuum pressure	1	12.01	0.9709	0.3573	0.0013	0.0005	0.9821	0.0013	0.7933	0.4027	1.20	1.31	0.2906
B-Time	1	0.2450	0.0198	0.8920	0.0000	0.0000	1.0000	0.0024	1.55	0.2525	0.2113	0.2298	0.6463
C- Temp	1	259.92	21.02	0.0025	61.05	26.43	0.0013	0.0420	26.69	0.0013	35.28	38.38	0.0004
AB	1	1.82	0.1474	0.7124	3.80	1.65	0.2403	0.0064	4.06	0.0837	0.0025	0.0027	0.9599
AC	1	19.80	1.60	0.2462	0.0900	0.0390	0.8491	0.0004	0.2539	0.6298	0.0400	0.0435	0.8407
BC	1	9.92	0.8025	0.4001	0.0625	0.0271	0.8740	0.0001	0.0635	0.8083	0.3600	0.3916	0.5513
A^2	1	5.07	0.4102	0.5423	0.0421	0.0182	0.8964	0.0082	5.17	0.0571	0.0855	0.0930	0.7692
B^2	1	0.2684	0.0217	0.8870	0.0026	0.0011	0.9740	0.0003	0.2164	0.6559	0.0360	0.0392	0.8487
C^2	1	43.05	3.48	0.1043	13.64	5.91	0.0454	0.0011	0.6841	0.4355	1.43	1.55	0.2526
Residual	7	86.55			16.17			0.0110			6.43		
Total	16	440.08			94.88			94.88			45.03		
C.V. %		4.69			22.30			7.30			6.24		
R^2		0.80			0.82			0.84			0.85		
Adjusted R^2		0.550			0.6105			0.6551			0.673		
Predicted R^2		-1.064			-0.1317			0.0235			0.211		

predicted for optimization of dependent variables (Y) are summerised in Table 2. Hardness showed significant at 5% level of significance on linear terms and quadratic terms.The reason behind the increase of hardness of prepared sample is may be due to evaporation of more water at high temperature during preparation, causes intermolecular molecules gets attracted and becomes compact, whereas the samples prepared at lower temperature becomes soft, less hardness and not died well also. The trend of increase in hardness of jaggery samples with temperature is similar to the results of edible coated jaggery samples reported by Madhu *et al.* (2018). The variations of hardness with different process parameters were graphically shown in 3-D surface plot Fig. 1 (D) and statistically proved in Table 2.

Conclusion:

The experimental data revealed that the jaggery samples obtained at vacuum pressure (Vp) 500 and time at 80 min with temperature of 110^0 C, have retained the maximum amount of TSS, Moisture content, Water activity and lesser variation in Hardness equivalent to traditional jaggery. Despite the advance in improvement in production process *i.e.*, incorporating of vacuum pan evaporator, there is no change in final quality of jaggery a part from this the new technology improved the energy requirement and decreased the jaggery making process too.

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