Effects of novel vacuum drying on orthodox and CTC tea processing

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ABSTRACT: Experiments were conducted on vacuum drying of tea leaves (orthodox, CTC) by following factorial design with three independent parameters: vacuum level, plate temperature and loading value, having three levels for their coded values (-1, 0, 1). The effects of these independent parameters were studied on the response, namely Δa (redness index of tea liquor), Δb (yellowness index of tea liquor) and aroma index (AI). Optimized values of independent parameters for orthodox tea were: vacuum level (670 mm Hg), plate temperature (75 °C), loading value (0.15 kg dry solid m^{-2}) and the corresponding values for CTC tea were: vacuum level (724 mm Hg), plate temperature (75 °C) and loading value (0.18 kg dry solid m^{-2}). Heat utilization efficiency for vacuum dryer was 2.14% for orthodox tea and the same figure for CTC tea was 1.23%.

KEYWORDS: Vacuum dryer; Design expert; Orthodox; CTC; Quality of tea

Introduction

Tea is one of the most popular and lowest cost beverage drinks that are enjoyed every day by hundreds of millions of people across all continents.[1] The three basic types of tea plant cultivated all over the world are (i) *C. sinensis* or China type; (ii) *C. assamica* or Assam type; and (iii) *C. assamica lasiocalyx* or Cambod type. Tea made from *Camellia sinensis* leaves is the most popular beverage consumed worldwide. Tea is made from young shoots, consisting of two or three leaves and the unopened terminal bud of tea plant *Camellia sinensis*. India is the second largest tea producing nation in the world and the third largest exporter of tea after Sri Lanka and China and nearly 25% of tea produced worldwide is consumed in India.[2] Drying is the final step in tea manufacture which refers to a process of water removal from a moist material by using heat as the energy input. The mechanism of drying is a complex phenomenon involving combined heat and mass transfer from the interior of food materials. It is done to stop the oxidation process and the leaf color turns from coppery red to black.[3] The objective of drying is primarily to achieve the target moisture content of 3 – 5% (wb), with minimal use of energy and the minimal loss in quality. The duration of the drying process needs to be kept as short as possible to avoid losses in quality. In tea production the most energy consuming process is drying and many volatile flavour compounds (VFC) in tea, are thermally unstable and may degrade during drying, which directly influences the flavour, taste and color qualities of tea beverage. The oxidation of catechins practically ceases when the leaf goes to the dryer, the condensation of theaflavins and thearubigins continues, so briskness, quality and strength are steadily decreasing. These changes are brought to a standstill only when the leaf has reached a certain degree of dryness. So, drying is a major challenge to reduce the moisture content to a certain low level while maintaining the quality attributes and at the same time economising the energy consumption.

Vacuum drying is a process in which materials are dried in a reduced pressure environment, which lowers the quantum of energy needed for drying. This is because in vacuum drying the heating medium is water, which has high specific heat capacity and smaller quantity of water at relatively lower temperature of 75 – 95°C can remove moisture from the tea leaves. On the other hand, in vibro-fluid bed dryer (VFBD) large quantity of air with relatively low specific heat capacity needs to be heated to reasonably high (120°C) temperature. The key benefits of vacuum drying include lower process temperatures, lower energy supply and hence greater energy economy, improved drying rates, and in some cases, less shrinkage of the product. The low pressure allows drying temperature to be reduced, which improves the colour and retains the aroma of tea leaves.

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Seeds were dried with a vacuum process and their results were compared to convective dryer.[4] Tests showed a 30% improvement in energy efficiency. Various types of tea dryers' (ECP dryer or, fluid bed dryer) performance were studied with different levels of inputs and simulation models for each type were constructed from a thin-layer drying regime.[5] The multi-stage fluid bed dryer with re-circulation was found to have the best combination of characteristics and is the type increasingly being used in the industry. Vacuum drying of mango pulp at various pulp thickness (2, 3 and 4 mm) and vacuum chamber plate temperatures (65°C, 70°C and 75°C) under 30 – 50 mm of mercury absolute pressure were carried out.[6] Energy consumption in various drying systems including hot-air convection, use of microwave pre-treatment with convection dryer, microwave drying, vacuum drying and infrared drying were studied.[7] The use of vacuum drying decreased the drying time and the energy consumption in comparison with pure convection drying. The study reported here is based on the following objectives:

1. To study the effects of independent parameters (vacuum level, plate temperature and loading value) on colour and aroma retention in orthodox and CTC black tea in vacuum drying.
2. Optimization of process parameters of vacuum drying for attaining high quality of black tea.
3. To execute an energy analysis of the vacuum dryer.

Methodology

A laboratory scale vacuum dryer, which is shown in Fig. 1, was used for carrying out drying experiments. The drying chamber of the vacuum dryer was provided with an inbuilt water tank, where hot water circulated between this tank and water supply tank. Pump was used for supplying the hot water. An electrode boiler was used for producing steam, which took care of heating the water kept in hot water supply tank. Hot water was circulated through pipes coiled over the surface of the vacuum drying chamber to preclude condensation of vapour on the sample during drying. Fermented tea leaves were put on Teflon coated tray and the tray was placed on the hot plate of the dryer. Hot plate temperature was maintained at 75°C, 85°C and 95°C by supplying hot water from the hot water supply tank. Controlling the temperature of the plate was done manually by regulating the temperature of hot water kept in the tank. A water ring vacuum pump was used to create necessary vacuum (670 – 730 mm Hg) inside the drying chamber. This pressure corresponded to the saturation temperature of water. Since the temperature of the heated plate was greater than the saturation temperature of water, pure water would boil inside the dryer. It was therefore possible to completely dehydrate the tea leaves.

Experiments were conducted for vacuum drying of tea leaves (orthodox, CTC) by following factorial design with three independent parameters: vacuum level, plate temperature and loading value, having three levels for their coded values (-1, 0, 1). The levels of vacuum inside the drying chamber (670, 700 and 730 mm Hg), the plate temperatures (75, 85 and 95°C) and the loading values (0.15, 0.2 and 0.25 kg dry matter m^{-2}) were varied and drying was conducted in such a way that the final moisture content of the product was obtained approximately in the range of 3 – 5% (wet basis). The bulk densities of fermented leaves were found to be 250 kg m^{-3} for CTC tea and 230 kg m^{-3} for orthodox tea. 2 - 3 mm of depth was maintained on the trays for vacuum drying and the bed porosities were 46% for CTC tea and 48% for orthodox tea. As the plate temperature s were higher than the evaporation temperature of tea leaves both for orthodox and CTC, there was likely to be a moisture gradient in the tea leaves over the tray. So, all moisture measurements were carried out by taking samples from various locations on the tray. The effects of independent parameters were studied on the response, namely Δa (redness index of tea liquor), Δb (yellowness index of tea liquor) and aroma index (AI). While calculating a and Δb values, distilled water was used as control. To find out the effects of the independent variables (X) on these responses, which were dependent variables (Y), quadratic model was fitted between Y and X.

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 \quad (1)$$

Where, b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23}, b_{11}, b_{22}, b_{33} are model constants. b_0 is the arithmetic mean response of 27 experiments and b_i is the estimated coefficient for the factor X_i. The interactions (X_1X_2, X_2X_3 and X_1X_3) show how the response value changes when two factors are simultaneously changed.

Colour Measurement

Freshly boiled 75 ml water was added into a pot containing 1.25 g dried tea sample. A lid was placed over the pot and after 3 minutes the infused tea was decanted into the beaker to measure colour values with the help of Hunter lab colorimeter (model: Colorflex EZ – 45/0). It gives L, a, b, L*, a*, b* and WIE values. Colour of tea is the most significant and sufficient quantification of tea quality.[8] The L, a, b type of scales simulate this as:

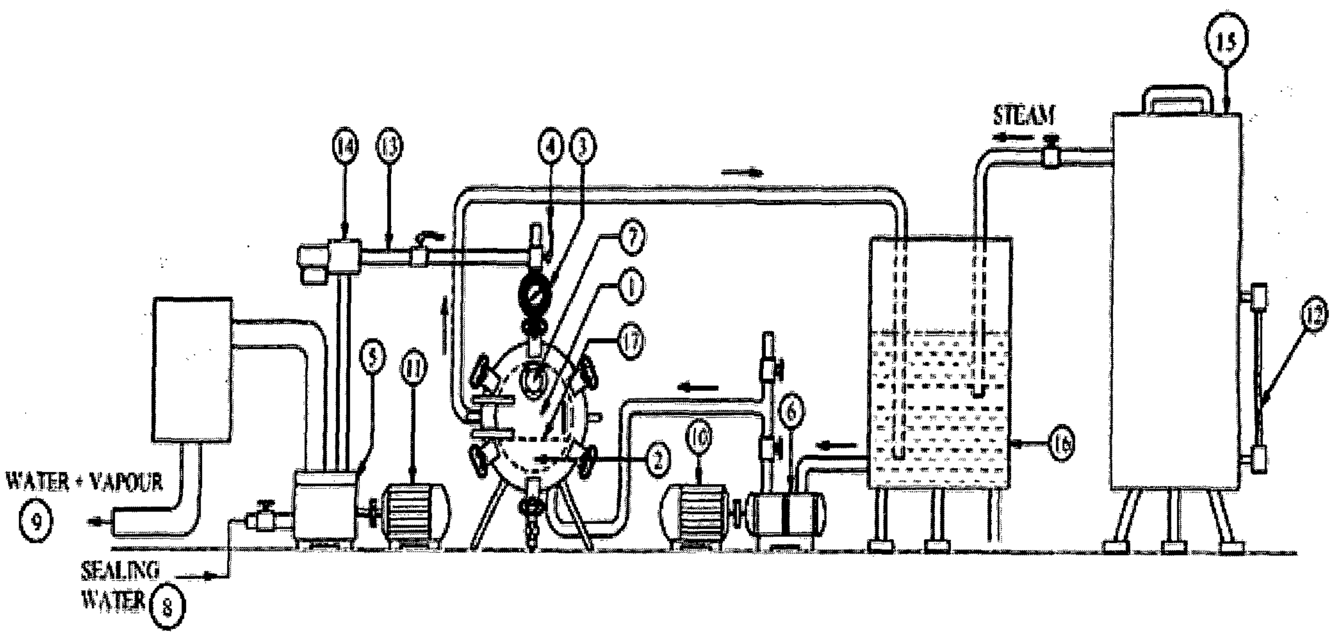

Fig. 1: Schematic diagram of vacuum drying set up: 1-vacuum drying chamber; 2-chamber lid; 3-vacuum gage; 4-release valve; 5-vacuum pump; 6-water pump; 7-watch glass; 8-vacuum pump sealing; 9-vacuum pump exhaust;10-water pump motor; 11-vacuum pump motor; 12-water level gauge; 13-vacuum break line; 14- vacuum connector; 15- boiler; 16-water tank; 17-drying tray.

L (lightness) axis – 0 is black, 100 is white.

a (red-green) axis – positive values are red; negative values are green and 0 is neutral

b (yellow-blue) axis – positive values are yellow; negative values are blue and 0 is neutral.

These scales can also indicate the color difference between a sample and a standard. Color difference is always calculated as sample minus standard and is frequently stated with a Δ symbol. Distilled water is taken as the standard. The values of L, a and b for distilled water are 49.76, -0.81, 12.77 respectively.

$\Delta L = L_{sample} - L_{standard}$	+ΔL means sample is lighter than standard
	-ΔL means sample is darker than standard
$\Delta a = a_{sample} - a_{standard}$	+Δa means sample is redder than standard
	-Δa means sample is greener than standard
$\Delta b = b_{sample} - b_{standard}$	+Δb means sample is yellower than standard
	-Δb means sample is bluer than standard

These values indicate how much a standard and sample differ from one another in L, a and b scales. The ΔL, Δa and Δb values are often used for quality control.

Aroma Index Measurement

Aroma index for the made tea was measured using Electronic nose *(ENVS, CDAC, Kolkata,). An electronic* nose can be a better alternative to conventional method for the measurement of tea flavour.[9] E-Nose can give tea taster like score within two minutes and it's easy to operate. To measure aroma index, 10 g of sample was used for an exposure of 2 minutes to obtain the aroma index observation with the electronic nose.

Results and Discussion

Analysis and Optimization of Orthodox Black Tea in Vacuum Drying

Full factorial design was used to investigate the joint influence of three independent parameters: vacuum level, plate temperature and loading value on the responses, namely Δa (redness index of tea liquor), Δb (yellowness index of tea liquor) and aroma index (AI). Optimization of the drying parameters was done on the basis of desired values of the dependent parameters. The moisture content of the product was targeted to be maintained in the range of 3 to 4% (wet basis). It was found in literature that, high quality black tea should have higher values of Δa and Δb.[10] Considering this fact, Δa, Δb and aroma index (AI) were maximized to obtain optimized process parameters for better quality of made tea.

Effects of Process Parameters on Redness Index (Δa) in Vacuum Drying of Orthodox Tea

The responses (colour and aroma) are measured for each experiment which is given in Table 1 for orthodox tea.

The regression equation between Δa, the redness index of tea liquor and coded values of independent variables is shown in Eq. (2)

$$\Delta a = 17.54 + 0.60x_1 + 0.78x_2 - 1.01x_3 - 0.96x_1x_2 + 0.34\, x_1x_3 + 0.22\, x_2x_3 - 1.11\, x_1^2 - 1.48\, x_2^2 - 0.59x_3^2 \quad (2)$$

($R^2 = 0.3572$), where x_1, x_2 and x_3 are the dimensionless coded values of independent variables X_1 (vacuum level), X_2 (plate temperature) and X_3 (loading value) respectively.

Observing the coefficients of x_1, x_2 and x_3 in Eq. (2) it is noted that,

1. Coefficient of x_3 (the coded value of loading) is the highest i.e. -1.01 and that is followed by x_2 (the coded value of plate temperature) and x_1 (the coded value of vacuum level) i.e. 0.78 and 0.60, respectively. Therefore direct effect of the plate temperature is the highest on the redness index of tea liquor, followed by the vacuum level and the inverse effect of the loading value.
2. Coefficients of x_1 and x_2 are positive but that of x_3 is negative, therefore increase in vacuum level and plate temperature would enhance the redness index

Table 1: Response values of each experiments of vacuum drying of orthodox tea

X_1	X_2	X_3	a	Δa	b	Δb	AI
1	0	-1	17.29	18.1	12.33	-0.44	1.7
1	0	1	16.38	17.19	13.56	0.79	4.3
1	0	0	18.12	18.93	11.64	-1.13	2.3
1	1	-1	14.79	15.6	15.82	3.05	3
1	1	1	9.76	10.57	17.84	5.07	3.7
1	1	0	11.45	12.26	16.84	4.07	5
1	-1	-1	14.85	15.66	15.06	2.29	2.5
1	-1	1	15.33	16.14	15.41	2.64	4.3
1	-1	0	15.62	16.43	14.32	1.55	3.3
0	-1	-1	12.01	12.82	16.53	3.76	9.2
0	-1	1	8.27	9.08	17.75	4.98	4.3
0	-1	0	13.87	14.68	16.41	3.64	7
0	0	-1	16.53	17.34	13.49	0.72	4.9
0	0	1	16.79	17.6	13.58	0.81	4.6
0	0	0	14.56	15.37	14.3	1.53	4.9
0	1	-1	18.37	19.18	12.28	-0.49	3.9
0	1	1	18.71	19.52	11.97	-0.8	9.4
0	1	0	19.1	19.91	12.68	-0.09	4.3
-1	0	-1	15.84	16.65	14.3	1.53	5
-1	0	0	14.23	15.04	14.84	2.07	4.9
-1	0	1	10.66	11.47	16.56	3.79	4.7
-1	1	-1	14.32	15.13	15.54	2.77	5.9
-1	1	0	13.46	14.27	15.76	2.99	6.9
-1	1	1	14.15	14.96	15.61	2.84	6
-1	-1	-1	14.85	15.66	15.52	2.75	8.3
-1	-1	0	14.66	15.47	15.84	3.07	8.1
-1	-1	1	12.57	13.38	16.99	4.22	7.7

of the tea liquor, whereas increase in loading value will reduce the redness index of the tea liquor. This is expected as loading value is a gross parameter reflecting bulk density, porosity and bed depth, more material on the tray leads to slower drying and lowering of the development of red colour.

Effects of Process Parameters on Δb (Yellowness Index) in Vacuum Drying of Orthodox Tea

The regression equation between Δb (the yellowness index of tea liquor) and the coded values of independent variables is shown in Eq. (3)

$$\Delta b = 0.34 - 0.43x_1 - 0.50x_2 + 0.44x_3 + 0.56x_1x_2 + 0.019x_1x_3 + 0.069x_2x_3 + 0.85x_1^2 + 1.59x_2^2 + 0.25x_3^2 \quad (3)$$

($R^2 = 0.4423$), where x_1, x_2 and x_3 are the dimensionless coded values of independent variables X_1 (vacuum level), X_2 (plate temperature), and X_3 (loading value), respectively.

Observing the coefficient of x_1, x_2 and x_3 in Eq. (3) it is found that,

1. Coefficient of x_2 (the coded value of plate temperature) is the highest i.e. -0.50 and this is followed by x_1 (the coded value of vacuum level) and x_3 (the coded value of loading) i.e -0.43 and +0.44, respectively. Therefore, the effect of the plate temperature is the highest on the yellowness index of tea liquor followed by the vacuum level and the loading value.
2. Coefficients of x_1 and x_2 are negative but that of x_3 is positive, therefore increase in vacuum level and plate temperature would reduce the yellowness index of tea liquor, whereas increase in the loading value would enhance the yellowness index of tea liquor. Again, this is expected as loading value is a gross parameter reflecting bulk density, porosity and bed depth, more material on the tray leads to slower drying and increasing of the development of yellow colour instead of red colour.

Effects of Process Parameters on Aroma Index (AI) in Vacuum Drying of Orthodox Tea

The regression equation (with coded values of independent variables) relating the aroma index to the transformed factors is shown in Eq. (4)

$$A.I = 5.01 - 1.36x_1 - 0.20x_2 + 0.089x_3 + 0.33x_1x_2 + 0.74x_1x_3 + 1.08x_2x_3 - 1.13x_1^2 + 1.40x_2^2 - 0.17x_3^2 \quad (4)$$

($R^2 = 0.7311$), where x_1, x_2 and x_3 are the dimensionless coded values of independent variables X_1 (vacuum level), X_2 (plate temperature), and X_3 (loading value) respectively.

Observing the coefficient of x_1, x_2 and x_3 in Eq. (4) it is observed that,

1. Coefficient of x_1 (the coded value of vacuum level) is the highest i.e. -1.36 and this is followed by x_2 (the coded value of plate temperature) and x_3 (the coded value of loading rate) i.e. -0.20 and +0.089. Therefore the effect of vacuum level is the highest on the aroma of tea liquor, followed by plate temperature and loading rate.
2. Coefficients of x_1 and x_2 are negative but that of x_3 is positive, therefore increase in vacuum level and plate temperature would reduce the aroma of tea liquor whereas increase in loading value would enhance the aroma of tea liquor. This is expected as loading value is a gross parameter reflecting bulk density, porosity and bed depth, more material on the tray leads to tempered drying and hence, the retention of the aroma compounds.

Optimization of Process Variables of Orthodox Black Tea in Vacuum Drying

Optimization of process parameters for vacuum drying of Orthodox tea was done by Design Expert software. Design Expert 7. 1 program was utilized and used for optimization of responses. The desired goal for each factor and response was chosen. The optimisation was done to maximize the redness index, the yellowness index of the tea liquor and the aroma index of dried tea. The optimum condition was selected at the maximum desirability by software itself which gave optimum condition of independent and dependent variables, which is shown in Table 2.

Analysis and Optimization of CTC Black Tea in Vacuum Drying

Values of independent and dependent variables data obtained from the experiments are shown in Table 3. Process parameters considered were vacuum levels, plate temperatures, loading values and the responses were Δa (redness index), Δb (yellowness index) and aroma index (AI)

Effects of Process Parameters on Δa (Redness Index) of CTC Black Tea in Vacuum Drying

The regression equation between Δa, the redness index of tea liquor and coded value of independent variables

Table 2: Optimized values of independent parameters and predicted dependent parameters of vacuum drying of orthodox tea

Vacuum level (mm Hg)	Plate temp. (°C)	Loading rate (kg dry solid m^{-2})	Δa	Δb	Aroma index	Desirability
677.67	75.00	0.15	14.1843	3.55877	8.66162	0.686
677.42	75.00	0.15	14.1331	3.59927	8.67084	0.686
677.67	75.10	0.15	14.2195	3.52423	8.61697	0.684
678.18	75.13	0.15	14.2954	3.46259	8.5959	0.684
673.35	75.00	0.15	13.6207	4.00393	8.72619	0.682

was obtained by using Design Expert 7. 1, and as shown in Eq. (5).

$$\Delta a=19.83 - 0.40x_1 + 0.42x_2 - 0.21x_3 - 0.75x_1x_2 - 0.003x_1x_3 + 0.15x_2x_3 - 0.35x_1^2 + 0.30x_2^2 -0.034x_3^2 \quad (5)$$

where, x_1, x_2 and x_3 are the dimensionless coded values of independent variables X_1 (vacuum level), X_2 (plate temperature), and X_3 (loading value) respectively.

For the predicted values of Δa by Eq. 5, when compared with experimental values given in Table 3, a value of R^2 =0.5494 was obtained.

Observing the coefficient of x_1, x_2 and x_3 in Eq. (5) it is noted that,

1. Coefficient of x_2 (the coded value of plate temperature) is the highest i.e. + 0.42 and this is followed by x_1 (the coded value of vacuum level) and x_3 (the coded value of loading value) i.e. -0.40 and -0.21, respectively. Therefore the effect of the plate temperature is the highest on the redness index of the tea liquor, followed by the vacuum level and the loading value.
2. Coefficients of x_1 and x_3 are negative but that of x_2 is positive, therefore increase in the vacuum level and the loading value will reduce the redness index of the tea liquor whereas increase in the plate temperature will enhance the redness index of the tea liquor. This is expected, as well in the case of orthodox tea, the loading value, being a gross parameter reflecting bulk density, porosity and bed depth, more material on the tray leads to slower drying and lowering of the development of red colour.

Effects of Process Parameters on Δb (Yellowness Index) of CTC Tea in Vacuum Drying

The regression equation between Δb, the yellowness index of tea liquor and the coded values of the independent variables was obtained by using Design Expert 7.1, as shown in Eq. (6)

$$\Delta b=-1.67 + 0.69x_1 + 0.063x_2 - 0.12x_3 + 0.42x_1x_2 - 0.41x_1x_3 - 0.32x_2x_3 + 0.051x_1^2 -0.97x_2^2 -0.30x_3^2 \quad (6)$$

where, x_1, x_2 and x_3 are the dimensionless coded values of independent variables X_1 (vacuum level), X_2 (plate temperature), and X_3 (loading value), respectively.

For the predicted values of Δb by Eq. (6), when compared with the experimental values given in Table 3, a value of R^2 =0.3332 was obtained.

Observing the coefficient of x_1, x_2 and x_3 in the Eq. (6) it is observed that,

1. Coefficient of x_1 (the coded value of vacuum level) is the highest i.e. +0.69 and that followed by x_3 (the coded value of loading) and x_2 (the coded value of plate temperature) i.e -0.12 and +0.063, respectively. Therefore, the effect of vacuum level is the highest on the yellowness index of the tea liquor, followed by the plate temperature and the loading value.
2. Coefficients of x_1 and x_2 are positive but that of x_3 is negative, therefore increase in vacuum level and plate temperature will enhance the yellowness index of tea liquor whereas increase in loading value will reduce the yellowness index of tea liquor. This again, is expected as loading value is a gross parameter reflecting bulk density, porosity and bed depth, more material on the tray leads to tempered drying and increasing of the development of yellow colour instead of red.

Effects of Process Parameters on Aroma Index of CTC Tea in Vacuum Drying

The regression equation between the aroma index of tea liquor and the coded value of the independent variables

Table 3: Response values of each experiments in vacuum drying of CTC black tea

X_1	X_2	X_3	a	Δa	b	Δb	AI
0	-1	-1	19.08	19.89	7.98	-4.79	3.9
0	-1	1	19.22	20.03	8.25	-4.52	2.5
0	-1	0	19.54	20.35	9.29	-3.48	3.7
0	0	-1	18	18.81	12.34	-0.43	1.7
0	0	1	18.09	18.9	12.94	0.17	2.7
0	0	0	18.38	19.19	12.55	-0.22	2.3
0	1	-1	20.49	21.3	9.35	-3.42	7.5
0	1	1	20.27	21.08	9.47	-3.3	7.4
0	1	0	20.17	20.98	9.35	-3.42	5.6
1	-1	-1	19.45	20.26	9.93	-2.84	8.6
1	-1	1	19.12	19.93	10.06	-2.71	6.8
1	-1	0	18.09	18.9	11.67	-1.1	14.8
1	0	-1	19.31	20.12	11.34	-1.43	4.3
1	0	1	17.43	18.24	10.12	-2.65	6.4
1	0	0	18.25	19.06	12.53	-0.24	5.8
1	1	-1	17.41	18.22	12.77	0	5.1
1	1	1	18.29	19.1	10.07	-2.7	3.9
1	1	0	18.7	19.51	10.58	-2.19	5.3
-1	-1	-1	18.3	19.11	10.65	-2.12	2.8
-1	-1	1	17.46	18.27	11.87	-0.9	3.7
-1	-1	0	17.58	18.39	9.51	-3.26	6.6
-1	1	-1	19.83	20.64	9.29	-3.48	3.6
-1	1	1	19.98	20.79	9.68	-3.09	3.1
-1	1	0	20.24	21.05	9.78	-2.99	5.4
-1	0	-1	20.25	21.06	8.78	-3.99	5.1
-1	0	1	19.66	20.47	8.28	-4.49	7.9
-1	0	0	19.96	20.77	8.75	-4.02	6.8

was obtained by using Design Expert 7.1, as shown in Eq. (7)

$$AI = 4.65+0.89x_1 - 0.36x_2+ 0.067x_3 -1.24x_1x_2-0.34x_1x_3+0.042x_2x_3+ 1.68x_1^2+0.73x_2^2-1.39x_3^2 \quad (7)$$

where, x_1, x_2 and x_3 are the dimensionless coded values of independent variables X_1(vacuum level), X_2 (plate temperature), and X_3 (loading value) respectively.

For the predicted values of AI by Eq. (7), when compared with the experimental values given in Table 3, a value of R^2 =0.3757 is obtained.

Observing the coefficient of x_1, x_2 and x_3 in Eq. (7) it is noted that,

1. Coefficient of x_1 (the coded value of vacuum level) is the highest i.e. +0.89 and this is followed by x_2 (the coded value of plate temperature) and x_3 (the coded value of loading) i.e. -0.36 and +0.067, respectively. Therefore the effect of vacuum level is the highest on the aroma index of made tea, followed by plate temperature and loading value.
2. Coefficients of x_1 and x_3 are positive but that of x_2 is negative therefore increase in vacuum level and loading value will enhance the aroma index of the made tea whereas the increase in the plate temperature will reduce the aroma of the made tea. This again, is expected as loading value is a gross parameter reflecting bulk density, porosity and bed depth, more material on the tray leads to

tempered drying and better retention of the aroma compounds.

Optimization of Process Variables of Vacuum Drying of CTC Tea

Optimization of process parameters for vacuum drying of CTC tea was done by Design Expert software. To perform this operation Design Expert 7.1 program was utilized and used for optimization of response. The desired goal for each factor and response were chosen. The optimization was done to maximize the redness index, the yellowness index of tea liquor and the aroma index of made tea. The optimum condition was selected at the maximum desirability by the software itself, which indicated optimum condition of independent and dependent variables, as shown in Table 4.

Comparative Study of Vacuum Drying of Orthodox and CTC Black Tea

Effects of independent parameters on responses on drying of orthodox and CTC are compared and following observations are made:

1. The value of the redness index (Δa) of CTC tea is high at moderate vacuum level (670 – 700 mm Hg) and high plate temperature (95 °C) and in orthodox tea its value is high at high vacuum level (730 mm Hg) and moderate temperature (85 °C).The reader should appreciate the distinction between orthodox and CTC tea. CTC tea is macerated, hence more like a pasty mass with broken leaves in between, where as orthodox tea is loose solids strewn over the heating surface. Red colour development is accompanied with high concentration of thearubigins which evaporate at high temperatures and high vacuum. In orthodox tea the red colour is associated with high vacuum as loosely strewn tea leaves fail to get the full effect of the plate temperature by contact. On the other hand, for CTC tea low vacuum accompanied with longer drying time and higher plate temperature account for fuller development of red colour. Effect of plate temperature is greater on the redness index of CTC than that on orthodox tea.
2. The value of the yellowness index (Δb) in CTC tea is high at high vacuum (724 mm Hg) and at moderate plate temperature (85 °C) and the same for orthodox tea is occurring at low vacuum (670 mm Hg) and extreme plate temperatures such as 75 and 95 °C. Generally speaking, milder heat treatment leads to fuller development of yellow colour. For CTC tea the pasty material at high vacuum is exposed to lower boiling point and shorter drying time, leading to low severity of the heat treatment. For orthodox tea, on the other hand, these considerations are not quite applicable for poor contact between the leaves and the heating surface. Moreover, the absolute values of Db are negative for CTC tea and positive for orthodox tea indicating more severity of heat treatment for CTC tea due to pasty consistency of the drying mass, leading to darker (bluish) colour.
3. Aroma of CTC is high at higher vacuum (730 mm Hg) level because of the effect of vacuum, the saturation temperature of water decreases leading to faster moisture removal and greater aroma retention in the complete macerated leaves but in orthodox, since the leaves are largely loose fragments so the escape of aroma is more at higher vacuum (730 mm Hg). Lower plate temperature leads to better retention of aroma for CTC tea but the effect of the same factor for orthodox tea is inconclusive due to the nature of irregular contact between the strewn leaves and the heating surface.

Table 4: Optimized values of independent parameters and predicted dependent parameters for vacuum drying of CTC tea

Vacuum level (mm Hg)	Plate temp. (°C)	Loading rate (kg dry solid.m^{-2})	Δa	Δb	Aroma index	Desirability
723.9	75.30	0.17	19.8576	-2.26371	9.26593	0.537
723.9	75.31	0.18	19.8538	-2.26022	9.27097	0.537
723.9	75.28	0.17	19.8638	-2.27098	9.26095	0.537
723.9	75.37	0.18	19.8442	-2.24493	9.26582	0.537
723.9	75.07	0.17	19.9005	-2.32945	9.26885	0.537

Table 5: Measured parameters during vacuum drying of orthodox tea

Parameters		
Initial MC (M_i), % (wb)-Fermented leaves		62.53
Final MC (M_f), %		3.59
Drying Time, min		40
Sp. Heat of water, kJ/kg.K		4.186
Sp. Heat of fermented tea, kJ/kg.K	$0.827 + (3.348 \times M_i)$	2.92
Temp of hot water in, °C		75
Temp of hot water out, °C		72
Initial temp of material, °C		26
Final temp of material, °C		70
Pressure, mm of Hg		670
Plate temperature, °C		75
Initial weight of material, kg		0.124
Final weight of material, kg		0.04
Density of fermented tea, kg/m^3		230
Mass Flow rate of water, m^3/s		0.3125×10^{-3}
Latent heat of water, h_{fg} in kJ/kg	$2501 + (1.88 - 4.186)T$	2328.05
Ambient temperature of water °C		23

Table 6: Calculation of energy required for drying and heat utilization efficiency for orthodox tea

Calculations		
Amount of water evaporated, kg	Initial wt - final wt, kg	0.084
Heat Input, kJ	$Q\, C_{pw}\, dT \times$ drying time	9418.50
Energy supplied per kg made tea (kJ/kg made tea		235462.50
Heat transferred to material for drying, kJ	$m\, C_p\, dT + M_w\, h_{fg}$	201.66
Energy required for drying per kg made tea (kJ/kg made tea)		5041.60
Heat utilization efficiency		2. 14 %

Energy Analysis in Vacuum Drying of Orthodox and CTC Tea

Table 5 and Table 7 give the relevant measured parameters during vacuum drying of orthodox and CTC tea respectively. Energy required per kg made tea for drying, heat utilization efficiency and heat input in vacuum drying for orthodox and CTC tea were calculated and are listed in Tables 6 and 8 respectively. As evident, the heat utilization efficiency values for both orthodox and CTC tea are very low. This is because only small quantity of tea sample was taken in vacuum drying, where as the whole rack of four trays were supplied with hot water and this caused heat loss from the exposed bottom and top surfaces of all trays lowering the heat utilization efficiency.

Conclusion

As presented, the effects of vacuum levels, plate temperatures and loading rates were studied on the response, namely Δa (redness index of tea liquor), Δb (yellowness index of tea liquor) and aroma index (AI) and it was found that the optimized values of

Table 7: Measured parameters during vacuum drying of CTC tea

Parameters		
Initial MC (M_i), % (wb)-Fermented leaves		68.66
Final MC (M_f), %		3.91
Drying Time, min		35
Sp. Heat of water, kJ/kg.K		4.186
Sp. Heat of fermented tea, kJ/kg.K	$0.827 + (3.348 \times M_i)$	3.13
Temp of hot water in, °C		89
Temp of hot water out, °C		82
Initial temp of material, °C		25
Final temp of material, °C		65
Pressure, mm of Hg		700
Plate temperature, °C		7576
Initial weight of material, kg		0.14822
Density of fermented tea, kg /m^3 Final weight of material, kg		0.05
Mass Flow rate of water, m^3/s		0.3125×10^{-3}
Latent heat of water, h_{fg} in kJ/kg	$2501 + (1.88 - 4.186)T$	2328.05
Ambient temperature of water, °C		23

Table 8: Calculation of energy required for drying and heat utilization efficiency for CTC tea

Calculations		
Amount of water evaporated, kg	Initial wt - final wt, kg	0.098
Heat Input, kJ	$Q\,C_{pw}\,dT \times$ drying time	19229.44
Energy supplied per kg made tea (kJ/kg made tea		384588.75
Heat transferred to material for drying, kJ	$m\,C_p\,dT + M_w h_{fg}$	235.56
Energy required for drying per kg made tea (kJ/kg made tea)		4711.12
Heat utilization efficiency		1. 23 %

independent parameters for orthodox tea were: vacuum level (670 mm Hg), plate temperature (75 °C), loading value (0.15 kg dry solid m^{-2}) and the corresponding values for CTC tea were: vacuum level (724 mm Hg), plate temperature (75 °C) and loading value (0.18 kg dry solid m^{-2}).

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