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Valorization of sweet orange peel residues via hot air drying and cariogenic grinding: Evaluation of color characteristics

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Abstract
Sweet orange (*Citrus sinensis*) belongs to the family Rutaceae. A 50-60% useful by-product is created during the sweet orange juice extraction process, which is a waste. When the peel is the primary by-product of sweet orange juice extraction. Currently, the peel is extensively utilized in animal feeds and biogas production. It might be a fascinating source of health advantages and medicinal material. Efforts were made to investigate the effect of drying temperature (50 °C, 70 °C, and 90 °C). Drying time (90 min., 120 min. and 150 min.) and grinding temperature (-15 °C, 5 °C and 25 °C) on changes in color properties (Colour L*, Colour a*, color b*, hue angle, chroma and ΔE) of sweet orange peel. The results revealed that parameters dropped as drying time and temperature increased, however, color analyses revealed the contrary. The grinding temperature was a crucial factor in the study, with lower grinding temperatures exhibiting the higher color parameters. Among all treatment combinations, the optimal treatment is 71 °C drying temperature, 150min drying time, and -15 °C grinding condition, which exhibited greater color properties.

Keywords: Sweet orange peel, hot air drying, cryogenic grinding, color characteristics

1. Introduction
India is the largest producer of horticultural crops and the processing of horticultural produce generates a vast amount of waste that contains useful compounds having medicinal, cosmetic, and nutritional value. Natural antioxidants, antimicrobials, and antidiabetic activities of fruits and vegetable processing wastes are currently attracting a lot of attention.

Citrus fruit is popular due to its characteristic flavor, taste, aroma, and multiple health benefits. Sweet orange (*Citrus sinensis* L.) is also called Moosambi in Kannada, Mousambi/Mosambi in Hindi or Urdu, Sathkudi in Tamil, and BathayaKaayalu in Telugu. Sweet orange (*Citrus sinensis*) belongs to the family Rutaceae and sub-family Aurantoideae (Milind and Dev, 2012) [12]. Sweet oranges mature in 9-12 months with the harvesting season in India being from October to March. The fruits of sweet orange (*Citrus sinensis* L.) are subglobose to round or oval in shape. Sweet orange diameter ranges from 5.7 to 9.5 cm with greenish-yellow to orange in color and is tightly skinned. The major constituents of sweet orange are juice (40-50%), flavedo (8-10%), and albedo (15-30%). The flavedo is the outer yellow sub-epidermal layer containing carotenoid pigments and numerous oil glands filled with aromatic essential oils. The albedo is the inner white spongy layer of parenchymatous cells closely adherent to the outer wall segment and having a thickness of around 0.16 to 1.43 cm. It has a high concentration of glucosides, flavonoids, pectin, and pectic enzyme. Most sweet orange and lime segments have one to three or four seeds linked to the septum wall by placentae. Oil (30-40%) and bitter limonoids are abundant in the seeds (Hashmi *et al*., 2012) [5].

After juice extraction, the waste from the sweet orange processing sector, such as peels, seeds, and pulps, which account for roughly 50-60% of the raw processed fruit, can be exploited as a possible source of valuable by-products. It represents more than 1.5 million tons per year of waste (El-Adawy *et al*., 1999) [1]. Citrus peels extract containing polymethoxylated flavones (PMFs) may help prevent diabetes as well as reduce the level of serum triglycerides (TG) and cholesterol. Citrus peels contain a high level of antioxidants more than vitamin E that contributes to the protection of DNA from cancer-causing damage and include degenerative diseases atherosclerosis, ischemic heart disease, ageing, diabetesmellitus, cancer, and immune suppressant (Shyura *et al*., 2005) [9].

Peel is the main by-product obtained from citrus fruit juice processing industries and is highly perishable (Silalahi, 2002) [10].

If not processed, the peels become waste and in turn, may become a possible source of environmental pollution. By-product recovery from fruit wastes can improve the overall economics of processing units and the problem of environmental pollution can also be reduced considerably (Silke and Ankit, 2009) [11]. It has very good nutritional value, which is evident by the presence of ascorbic acid, total phenolic compounds, limonene, naringenin, carotenoids, fiber, minerals, and many Phyto-chemicals with antimicrobial, antioxidant, antibacterial, antiviral, anti-yeast and antimutagenic properties, which states an ideal substrate for production of value-added products as drug or as a food supplement (Mohnen, 2008) [7]. Therefore, there is a need to optimize the drying and grinding conditions to produce high-quality dried sweet orange by-products as value-added product ingredients.

The objective of the present work was to evaluate color characteristics of sweet orange peel powder obtained from different drying and grinding methods.

2. Materials and Methods

Sweet orange peel was collected from the juice processing industry in Junagadh, Gujarat. Then, the peels were cut into small pieces (30x10 mm). After that, the peel surface moisture was removed, followed by hot air-drying at different temperatures (50 °C, 70 °C, 90 °C) and time (90min., 120min., 150min.) and grinding temperature (-15 °C, 5 °C, 25 °C).

2.1 Experimental Design

The conditions for obtaining the accurate analysis of color characteristics from the sweet orange peel were optimized by using a central composite design, response surface methodology (RSM). The design was composed of 19 experiments structured in three blocks with three levels (−1, 0, +1). Each experiment was carried out in duplicate. The independent variables were drying temperatures (50 °C, 70 °C, 90 °C), drying time (90 min., 120 min., 150 min.), and grinding temperature (-15 °C, 5 °C, 25 °C). Table 1 shows the experimental design made by design expert 11 software.

Table 1: Coded and Uncoded parameters of central composite rotatable design for hot air drying and grinding process of lime and sweet orange peel

Run	Treatment	Coded variable			Uncoded variables		
					Hot air tray drying		
		X_1	X_2	X_3	Drying temperature (°C)	Drying time (min.)	Grinding temperature (°C)
1	12	0	+1	0	70	150	5
2	19	0	0	0	70	120	5
3	9	-1	0	0	50	120	5
4	1	-1	-1	-1	50	90	-15
5	16	0	0	0	70	120	5
6	15	0	0	0	70	120	5
7	2	+1		-1	90	90	-15
8	7	-1	+1	+1	50	150	25
9	13	0	0	-1	70	120	-15
10	11	0	-1	0	70	90	5
11	17	0	0	0	70	120	5
12	18	0	0	0	70	120	5
13	10	+1	0	0	90	120	5
14	6	+1	-1	+1	90	90	25
15	8	+1	+1	+1	90	150	25
16	3	-1	+1	-1	50	150	-15
17	4	+1	+1	-1	90	150	-15
18	5	-1	-1	+1	50	90	25
19	14	0	0	+1	70	120	25

2.2 Estimation of color analysis

The Lovibond colorimeter RT850i was used to take measurements of the colour of sweet orange peel powder. A CIELAB scale L*, a*, b* scale Lovibond colorimeter (Make: Lovibond) installed at college of food processing technology & Bio- energy, Anand Agricultural University, Anand was used for colour analysis of sweet orange peel powder as shown in Low L* (0-50) values indicates dark and a high value (50-100) indicates light. Positive a* values indicate red and a negative value indicates green. Positive b* values indicate yellow and a negative value indicates blue. The L* value for each scale therefore indicates the level of light or dark, the a* value indicates redness or greenness and the b* value indicates yellowness or blueness. All three values are completely needed to judge the colour. The instrument was calibrated and L*, a*, and b* values were recorded for three replicates of each sweet orange and lime peel sample for analysis.

Total colour difference was calculated using following Eq. (1.1), where subscript “o” refers to the colour reading of fresh sweet corn kernel. Fresh sweet corn kernel was used as the reference and a larger ΔE denotes greater colour change from the reference material.

$$\Delta E = \sqrt{(L_o{}^* - L^*)^2 + (a_o{}^* - a^*)^2 + (b_o{}^* - b^*)^2} \qquad \ldots(1.1)$$

Where, L* is degree of lightness to darkness, L_o* is initial value of L*, a* is degree of redness to greenness, a_o* is initial value of a*, b* is degree of yellowness to blueness and b_o* is initial value of b*.

Chroma was expressed as $(a^{*2} + b^{*2})^{1/2}$ for providing more information regarding spatial colour distribution (Ihl *et al*., 1994) [12].

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}} \qquad \ldots(1.2)$$

Browning index (BI) is a measure of purity of brown colour and provide information regarding browning (Lopez-malo *et al*., 1998) [14].

$$\text{Browning Index}=\frac{[100(x-0.31)]}{0.17} \quad (1.3)$$

Where,

$$x=\frac{(a^*+1.75L^*)}{(5.645L^*+a^*-3.012b^*)} \quad (1.4)$$

3. Results and Discussion

3.1 The effect of different drying and grinding techniques on the colour properties of sweet orange peel powder

Figure 1 shows response surface graph of colour properties. Effect of drying temperature, drying time and grinding temperature on colour properties found significant effect (Fig, 1(A-L)).

3.1.1 Effect of tray drying on colour L* properties of sweet orange peel powder

Colour is an important part of food quality, because the color of food is consumers first appraise when making purchasing decisions. The results of color changes in fresh samples for tray drying, and grinding conditions were given in Table.1. The colour L* value was significantly affected by different drying temperature, drying time and grinding temperature (p<0.001) and resulted with a 44.83 to 65.85 decrease (Fig. 1). The lowest L* value (44.83) obtained from 90°C drying temperature, 150 min. drying time and 25°C grinding temperature treated sample which had darker color than other treatment. The regression analysis and ANOVA results for the colour L* of sweet orange peel powder are shown in the Table 2. It can be seen from the table, that the linear effect of drying temperature (p<0.001), drying time (p<0.001) and grinding temperature (p<0.05) negatively significant on colour L* of sweet orange peel powder in hot air drying methods. The small value of coefficient of variation (2.34) for colour L* in tray dried sweet orange peel powder explained that the experimental results were precise and reliable (Table 2).

3.1.2 Effect of tray drying on colour b* of sweet orange peel powder

The colour b* value was significantly affected by different drying temperature, drying time and grinding temperature (p<0.001) and resulted with a 73.51 to 35.21 (Table 1) decrease. The highest b* value (73.51) obtained from 50°C drying temperature, 90 min. drying time and -15°C grinding temperature treated sample which had darker color than other treatment. The lowest b* value (35.21) obtained from 90°C drying temperature, 150 min. drying time and 25°C grinding temperature treated sample which had darker color than other treatment. The regression analysis and ANOVA results for the colour b* of sweet orange peel powder are shown in the Table 2. It can be seen from the table, that the linear effect of drying temperature (p<0.001), drying time (p<0.001) and grinding temperature (p<0.01) negatively significant on colour b* of sweet orange peel powder in tray drying methods. The small value of coefficient of variation (5.08) for colour b* in tray dried sweet orange peel powder explained that the experimental results were precise and reliable (Table 2).

Colour L* and b* values decreased with increase in temperature. This was in line with the result of researchers (Ghanem *et al*., 2012 and Geraci *et al*., 2017) [3, 4]. whereas higher temperatures levels decreased sample lightness or yellowness during drying. This could be associate with the damage of carotenoids and flavonoids pigments of bitter orange peel which are responsible for the yellow and orange color of the biomaterial. Farahmandfar *et al*., (2019) [2] found similar result colour L* (50.24 to 66.67) and colour b* (69.53 to 75.14) decreased with increase in temperature and different drying method.

3.1.3 Effect of tray drying on colour a* of sweet orange powder

The colour a* value was significantly affected by different drying temperature, drying time and grinding temperature (p<0.001) and resulted with a 22.36 to 36.73 (Table 1) increase. The highest a* value (36.73) obtained from 90°C drying temperature, 150 min. drying time and 25°C grinding temperature treated sample which had darker color than other treatment. The lowest a* value (22.36) obtained from 50°C drying temperature, 90 min. drying time and -15°C grinding temperature treated sample which had darker color than other treatment.

The regression analysis and ANOVA results for the colour a* of sweet orange peel powder are shown in the Table 2. It can be seen from the table, that the linear effect of drying temperature (p<0.001) and drying time (p<0.01) positively significant on colour a* of sweet orange peel powder in tray drying methods. The small value of coefficient of variation (3.68) for colour a* in tray dried sweet orange peel powder explained that the experimental results were precise and reliable (Table 2).

All drying treatment caused reduction in the value of a* (greenness/redness), compared to those of fresh bitter orange peel, which indicated a lower redness and more carotenoid loss in dried samples (Ghanem *et al*., 2012) [3]. According to Reza *et al*., (2019) [14] colour a* (9.63 to 32.58) increased with increase in temperature and different drying method.

3.1.4 Effect of tray drying on chroma, browning index and total colour difference of sweet orange peel powder

The chroma of dried sweet orange peel powder was found varied from 50.27 to 76.83 in tray drying (Table 1). The regression analysis and ANOVA results for the chroma of tray dried sweet orange peel powder is shown in the Table 2. Quadradic model was fitted significant at p<0.001 level in hot air drying method. The small value of coefficient of variation (3.55) for chroma in tray dried sweet orange peel powder Table 2. Chroma decreases as the drying temperature, drying rime and grinding temperature increases according to table 1. The color parameter is BI which displays the purity of brown color in enzymatic and non-enzymatic browning processes (Saricoban *et al*., 2010) [8]. The BI of dried sweet orange peel powder was found varied from 183.39 to 294.90 in tray drying (Table 1). The regression analysis and ANOVA results for the BI of tray dried sweet orange peel powder is shown in the Table 2. The small value of coefficient of variation (5.38) for BI in tray dried sweet orange peel powder. BI increase as the drying temperature, drying rime and grinding temperature increases according to Fig. 1. High moisture content of fresh sweet orange peel would elevate enzymatic degradation which could enhance brown color in material. Reza *et al*., 2019 [14] found similar result BI (231.88 to 293.10) decreased with increase in temperature and different drying method. The total color difference (ΔE) is another color index which shows the degree of overall color change in dried samples with respect to the color of fresh sweet orange peel. Dried products with excellent quality should have a low ΔE value. The total colour difference of dried sweet orange peel powder was found varied from 5.47 to 51.36 in tray drying (Table 1). The regression analysis and ANOVA results for the total colour difference of tray dried sweet orange peel powder is shown in the Table 2. The higher value of coefficient of variation

(11.91) for total colour difference in tray dried sweet orange peel powder explained that the experimental results were not precise and reliable (Table 2). According to Reza *et al*., (2019) [14] total colour difference (19.42 to 31.21) noted in temperature and different drying method.

4. Conclusion

The present investigation is the first to examine the effects of various drying temperatures, drying periods, and grinding temperatures on the colour features of sweet orange peel under varied situations. In summary, low drying temperature and low grinding temperature samples showed the most colour brightness and yellowness, as well as the least amount of change in ΔE. Moreover, Sweet orange peel powder obtained by 71 °C drying temperature, 150 min. drying time and -15 °C grinding temperature with LN2 cooling had significantly higher colour properties compared to all other treatments. Color properties are found to be desirable in hot air drying and cryogenic grinding and these properties of sweet orange peel powder are important in storage packaging and handling/ transportation. Therefore, our outcomes could offer a useful data in favor of developing a process for drying and low temperature grinding combination of sweet orange peel and cryogenic grinding could be suggested as a potential approach for producing an excellent nutritional content with supreme color quality compare to normal grinding.

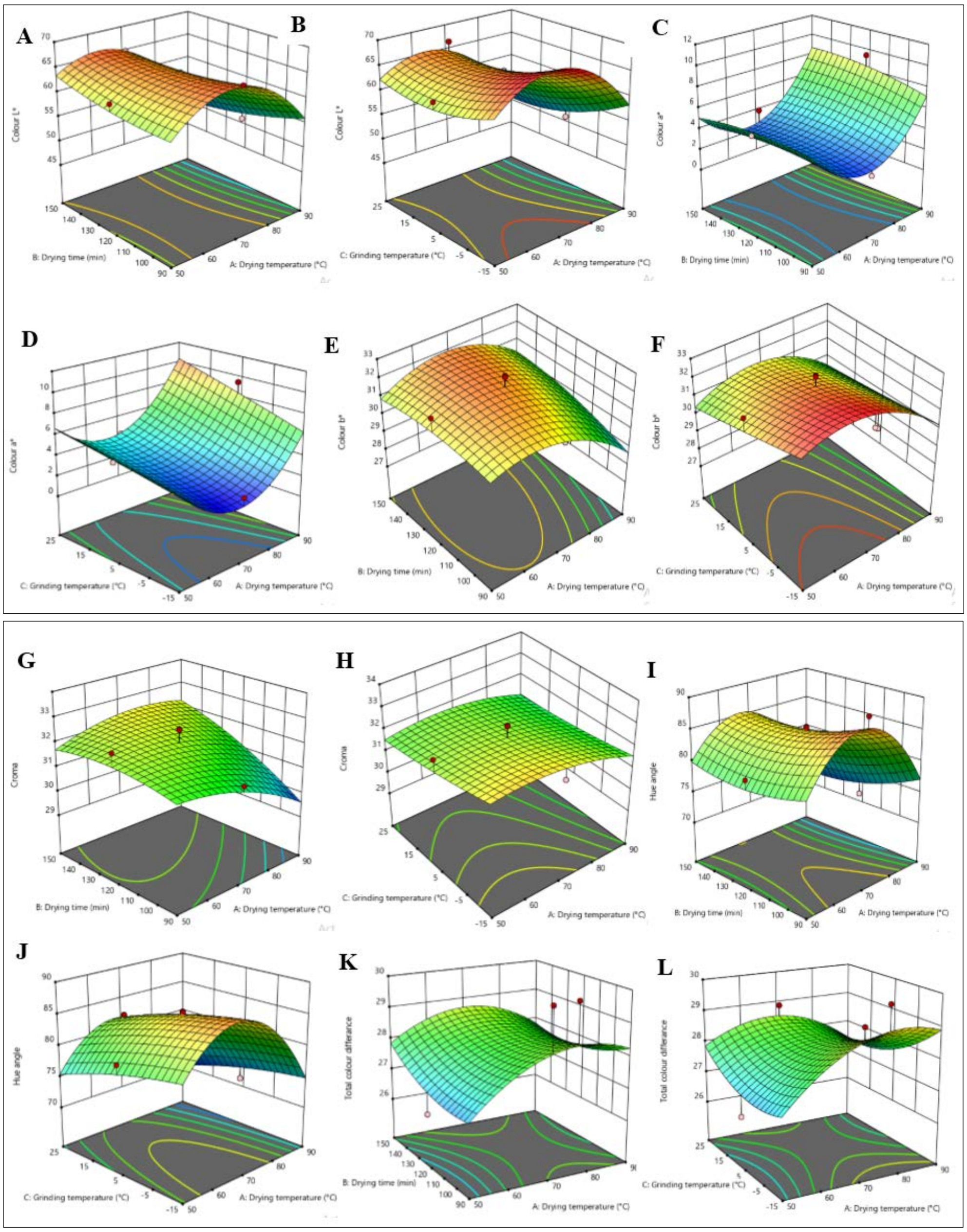

Fig 1: Effect of drying temperature, drying time and grinding temperature on colour properties

Table 1: Experimental value of milling loss and colour properties of sweet orange peel powder dried by tray dryer

Sr. No.	Std. run	Drying Temperature (°C)	Drying Time (min.)	Grinding Temperature (°C)	colour L*	Colour a*	Colour b*	Croma	BI	ΔE
SOTD1	12	70	150	5	52.37	30.72	47.63	56.68	211.23	35.7
SOTD2	19	70	120	5	55.43	27.36	57.43	63.61	254.96	25.16
SOTD3	9	50	120	5	64.36	23.98	71.23	75.16	282.83	8.64

SOTD4	1	50	90	-15	65.85	22.36	73.51	76.83	286.40	5.47
SOTD5	16	70	120	5	55.57	27.52	57.44	63.7	253.98	25.12
SOTD6	15	70	120	5	55.61	27.81	57.52	63.69	254.52	25.13
SOTD7	2	90	90	-15	51.8	31.48	43.52	53.71	190.25	39.67
SOTD8	7	50	150	25	60.07	23.89	67.72	71.81	294.90	13.58
SOTD9	13	70	120	-15	58.67	25.14	61.47	66.41	256.84	19.59
SOTD10	11	70	90	5	60.71	24.56	63.81	68.37	257.14	16.5
SOTD11	17	70	120	5	55.67	27.76	57.63	63.97	254.83	24.99
SOTD12	18	70	120	5	55.62	27.55	57.65	63.89	255.22	24.94
SOTD13	10	90	120	5	48.73	34.82	38.76	52.1	183.39	46.06
SOTD14	6	90	90	25	50.37	32.8	41.67	53.03	188.92	42.25
SOTD15	8	90	150	25	44.83	36.73	35.23	50.89	186.51	51.36
SOTD16	3	50	150	-15	62.38	23.14	69.92	73.64	290.25	10.33
SOTD17	4	90	150	-15	45.17	34.12	36.92	50.27	191.84	48.99
SOTD18	5	50	90	25	64.71	23.89	71.87	75.73	284.72	7.96
SOTD19	14	70	120	25	52.68	28.57	52.34	59.62	239.72	31.02

Table 2: Analysis of variance (ANOVA) and regression coefficients for response surface quadratic model of different colour properties of sweet orange peel powder by using tray dryer.

Source	Colour L*	Colour a*	Colour b*	Croma	BI	ΔE
Intercept	55.90***	27.62***	57.12***	63.51***	249.25***	25.26***
X_1	-7.65***	5.27***	-15.82***	-11.32***	-49.82***	18.23***
X_2	-2.86***	1.35**	-3.70***	-2.44**	-3.27	4.81***
X_3	-1.12*	0.9640	-1.65**	-0.9780	-2.08	2.21**
X_1X_2	-0.51	0.7238	-0.6625*	0.1913*	-1.86	0.9938*
X_1X_3	0.21	0.2063	0.0375	0.3588	-1.20	-0.0987
X_2X_3	-0.01	0.0638	-0.0500	0.0713	0.2927	0.0688
X_1^2	0.2404	1.75*	-1.61	0.4565	-9.33	1.85
X_2^2	0.2354	-0.0134	-0.8888	-0.6485	-8.25	0.5986
X_3^2	-0.6296	-0.7984	0.2962	-0.1585	5.85	-0.1964
R^2	0.9780	0.9708	0.9737	0.9675	0.9436	0.9760
Adj-R^2	0.9560	0.9415	0.9474	0.9350	0.8873	0.9520
Pred-R^2	0.8216	0.7478	0.7967	0.7425	0.6121	0.8118
Adeq Precision	24.5332	20.2217	20.5397	18.0806	11.6320	22.1061
F-value	44.42	33.21	37.03	29.81	16.75	40.71
Lack of fit	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
C.V. %	2.34	**3.68**	**5.08**	**3.55**	**5.38**	**11.91**

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