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Physico-Chemical Properties of Red Pepper (*Capsicum annuum* L.) as Influenced by Different Drying Methods and Temperatures

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Abstract: An experiment was carried out in the laboratories of the Department of Food Engineering, Department of Vegetable Science, and Department of Plantation Spices Medicinal and Aromatic crops, Bidhan Chandra Krishi Viswavidyalaya (BCKV), West Bengal, India. The work was performed during 2018–2019 and 2019–2020 with different drying methods including sun drying, solar drying and oven drying. In oven drying, different temperatures such as 50, 55, 60, 65, and 70 °C were considered. A randomized complete block design (RCBD) was designed with seven treatments and three replications. Experimental results were significantly varied among the treatments as influenced by different drying methods and temperatures. Minimum time taken (480 min) to reach safe moisture content was recorded in T_7 (oven drying at 70 °C), whereas maximum values in color components such as L* value (24.55), a* value (32.14), b* value (20.53), and pungency score (7.85) were recorded in T_6 (oven drying at 65 °C). However, the highest texture (1180.81) was observed in T_1 (sun drying). Biochemical parameters were significantly varied among the treatments. The maximum amounts of ascorbic acid (56.06 mg/100 g) and oleoresin content (10.72) were found in T_3 (oven drying at 50 °C), whereas minimum values of biochemical parameters were recorded by T_1 (sun drying) and T_2 (solar drying) methods, respectively. Mathematical relationships were found in different drying methods and temperatures. Models such as the Lewis, Page, Modified Page, and Henderson and Pabis models were selected to fit the data. Maximum R^2 value (0.9835) was found in both the Page and Modified Page models with similar values of drying method and temperature at 65 °C. This value was the highest among all models in all drying temperatures. However, the lowest χ^2, and $RMSE$ values (0.000818 and 0.027261, respectively) were recorded with the Page model.

Keywords: ascorbic acid; red pepper; physicochemical properties; oleoresin; oven drying; solar drying; sun drying

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1. Introduction

India is known for the production, consumption, and export of quality spices around the world. Chilli (*Capsicum annuum* L.) or red pepper is one of the key spices with a wide range of diversities [1], and it is consumed beyond every other spices. The preliminary moisture content of fresh red chillies varies from 300% to 400% (db) or 70–80% (wb), which is extremely high for processing and long duration storage [2]. Hence, reducing moisture in chilli to a secure level of 8–9% (db) becomes obligatory before their processing and storage. Drying is one of the most efficient and extensively utilized processes for any biological product. It is a process of synchronized heat and mass transfer in a multiphase arrangement. Customarily, dried chilli is obtained by sun drying fresh ripe chilli [3]. This drying method takes more than 3–5 days, subject to the weather setting, to obtain the requisite moisture content (8–10% wb). Due to this elongated period of time and straight exposure to air and light, an inferior quality dried chilli is usually produced, which primarily includes red color fading, browning pigmentation, and loss of vitamin C [4]. Moreover, it is one of the oldest methods of food preservation [5]. In view of the fact that dried chilli is vulnerable to fungal abundance, this process creates encouraging conditions for mycotoxins infectivity [6]. To avert fungal proliferation, diverse drying methods have been employed for dry chilli processing. To improve the quality of dried chilli, some mechanical, solar, and oven dryers have been introduced in order to reduce the drying time [7]. It has been found that the elevated temperatures resulted in reduced drying time and arise in the effectual moisture diffusivity [8]. Owing to the extended drying process, the problems of dark coloration, flavor loss, and diminished rehydration ability occurs. Prolonged shelf life, product diversity, and significant volume reduction are the reasons for the popularity of dried fruits and vegetables, and this could be extended further with improvements in product quality and process applications [9]. To thwart major quality loss and to accomplish faster and more effective dehydration, an assortment of drying techniques have been developed. These superior methods could boost the current degree of acceptance of dehydrated foods in the market [10]. However, using a too-high temperature for drying produces a low-quality chilli with considerable loss in volatile compounds, nutrients, and color [11]. Mechanical drying methods such as oven drying, fluidized bed drying, and microwave drying methods provide an enhanced product with more consistent quality, taking less time and minimizing crop losses. The fruits are usually dried in continuous or batch type dryers by exposing them to a forced current of air at a temperature of 50–60 °C, thereby dropping their moisture content to 8–9% (db).

2. Materials and Methods

Freshly harvested chillies (BCCH Selection-4) were procured from the research field. The harvested fruits at the red ripe stage were brought to the laboratory and kept in the shade for one hour to remove the field heat. The bruised, diseased, and damaged chillies were discarded, and the sound ones were washed with tap water to remove adhered dust, followed by drying. The experiment was conducted jointly in the laboratories of the Department of Food Engineering, Department of Vegetable Science and Department of Plantation Spices Medicinal and Aromatic Crops, BCKB, West Bengal, India. The entire work was performed during 2018–2019 and 2019–2020, with the following treatments: T_1 (sun drying), T_2 (solar drying), T_3 (oven drying temperature at 50 °C), T_4 (oven drying temperature at 55 °C), T_5 (oven drying temperature at 60 °C), T_6 (oven drying temperature at 65 °C), and T_7 (oven drying temperature at 70 °C) with different drying methods such as sun drying, solar drying, and oven drying. A randomized complete block design (RCBD) with seven treatments (T_1 to T_7) and three replications (R_1 to R_3) was laid out to conduct the experiment with a sample size of 500 g each.

2.1. Drying Methods

2.1.1. Sun Drying

Black polyethylene sheets were entirely cleaned, and the samples were positioned under the sun throughout the entire day time with an initial moisture content ranging from 76.87% to 80.68% (wb). Samples were prearranged for regular turnings to achieve uniform drying. The loss of moisture was recorded after an hour with an electronic balance, which works in similar way as a thermogravimetric analytical measuring equipment (TGA) used nowadays. Drying was continued until the sample attained a steady weight. The drying time and drying rate depends upon the ambient temperature. Ambient temperature and relative humidity were also measured periodically. The moisture content values were calculated on a dry matter basis (db) and expressed in % (Figure 1A).

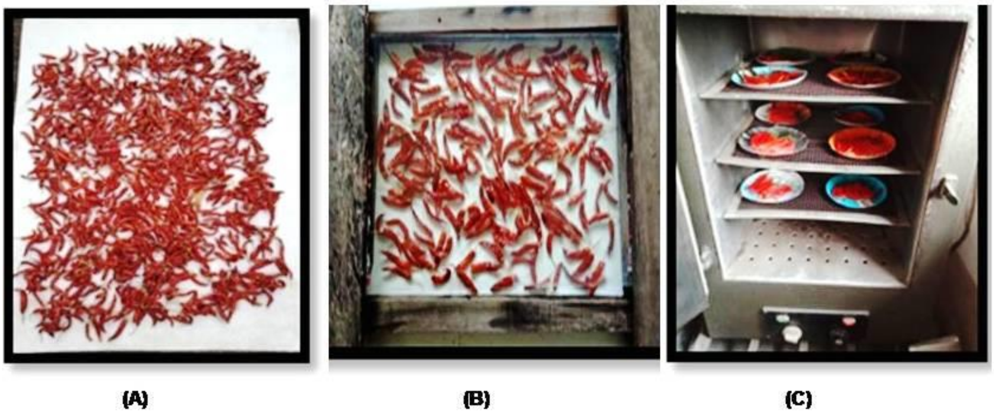

Figure 1. (**A–C**): (**A**): -sun drying; (**B**): -solar drying; and (**C**): -oven drying.

2.1.2. Solar Drying

Solar drying was carried out using the sample of chillies placed in a single layer on black polythene sheet. Samples were covered with glass films. The loss of moisture was recorded at 60 min intervals for the entire drying period. The drying was performed constantly until the sample attained a fixed weight. The weight of the sample was measured on a precise electronic balance. The moisture content was calculated on dry matter basis (db) and expressed in % (Figure 1B).

2.1.3. Oven Drying

Chilli samples were kept in the chambers of the hot air oven and the thermostat was set at 50, 55, 60, 65, and 70 °C as per the prerequisite of the experiment on that particular day. The initial moisture content of fresh chillies was around 75.87% to 81.37%. Readings of moisture content were taken at an interval of 60 min of drying with a precise electronic balance calculated on dry matter basis (db) and expressed in %. The experiment was carried out until the sample attained a constant weight (Figure 1C).

2.2. Physico-Chemical Analysis

2.2.1. Time Taken to Reach Safe Moisture (8–10%)

The moisture content was estimated by the method described by standard air oven method as per AOAC (1995) [12]. The dried samples were transferred to desiccators and cooled to room temperature. The weight loss during drying was counted to calculate the moisture content of the sample and was represented on the basis of wet weight of the sample.

$$\text{M.C (wb)} = (\text{Mw}/\text{M}) \times 100 \quad (1)$$

where, M.C (wb) = Moisture content, % wb; Mw = Mass of water, g; M = Initial mass, g.

2.2.2. Colour Values (L*, a*, b*)

The L*, a*, and b* color values were observed by a Hunter colorimeter. The colorimeter (Make: Color Flex EZ spectrophotometer) was operational with an 8 mm measuring head and AC illumination (6774 K). The meter was calibrated using the manufacturer's standard white plate. All changes of color were quantified in the L*, a*, and b* c color space. L* refers to lightness of the fruit color ranging from black (=0) to white (=100). A negative value of a* represents a green color where the positive value indicates red-purple color. A positive value of b* indicates a yellow color and the negative value a blue color [13].

2.2.3. Texture Analysis (g)

The textural property of dried red peppers was calculated as a puncture force, which was a measure of the hardness of the product surface as measured through a texture analyzer (TA-XT Plus; Stable Micro Systems, Surrey, UK) using a 2 mm cylindrical probe. The puncture force that was necessary to rupture the dried red pepper was recorded. Speeds of 2.0 mm/s and a penetration distance of 5.0 mm were used to puncture the samples. The data were presented as means for each treatment.

2.2.4. Pungency Measured by Sensory Evaluation in Hedonic Scale or Organoleptic Score

Pungency was evaluated by tasting the chillies with a randomly selected 10 people of different age groups (heterogeneous) peoples, and they had given the rating of hotness (pungency) on a hedonic scale range from (1—extremely dislike and 9—extremely like) in accordance with the method suggested by Joshi [14].

2.2.5. Ascorbic Acid (mg/100 g)

Ascorbic acid content of fresh and dry chilli was estimated by the volumetric method described by Sadasivam and Balasubramanian [15]. The working standard ascorbic acid solution (5 mL) was taken into a 100 mL conical flask with an addition of 10 mL of 4% oxalic acid followed by titration against the dye (V1 mL). Pink color appears as an endpoint. The quantity of dye consumed corresponds to that of ascorbic acid. The sample was extracted in 4% oxalic acid, and the final volume was made up to 100 mL and then further centrifuged. Then, 5 mL of this supernatant was pipetted out and titrated against the dye (V2 mL) by adding 10 mL of 4% oxalic acid to it.

The amount of ascorbic acid was calculated by using formulae as follows:

$$\text{mg/100 mL sample} = (0.5\ \text{mg/V1 mL} + \text{V2 mL/5 mL} + 100\ \text{mL} \times 100/\text{Wt. of the sample}) \quad (2)$$

A similar method has also been followed by our research group in a recent study [16] while estimating ascorbic acid from fresh onion.

2.2.6. Oleoresin (%)

The oleoresin was estimated by following the procedure of Rangana [17]. A pinch of washed glass wool was added to a glass column and pushed into the bottom. A total of 10 g of delicately powdered chilli sample was transferred into the column. Then, cold acetone was supplemented at a ratio of 1:10 (weight: volume), and the extract was collected in a porcelain dish followed by its evaporation over a water bath, drying, and weight measurement. The amount of oleoresin was calculated by the formula:

$$\%\ \text{Oleoresin} = [(W3 - W2)/W1] \times 100 \quad (3)$$

where W1 = weight of the sample taken, W2 = weight of the empty porcelain dish, and W3 = weight of the porcelain dish + sample extract after drying.

2.2.7. Mathematical Models

Four different thin layer mathematical models were applied to the sun, solar, and oven drying of chillies (Table 1).

Table 1. Different mathematical models and their expression.

Name of Model	Expression	References
1. Lewis	$MR = \exp(-k\,t)$	[18,19]
2. Page	$MR = \exp(-k\,t^n)$	[20,21]
3. Modified Page	$MR = \exp(-k\,t)^n$	[18,20]
4. Henderson and Pabis	$MR = a \exp(-k\,t)$	[18,21]

2.3. Statistical Analysis

The data were analyzed statistically by following the procedure outlined by Panse and Sukhatme [22]. The appropriate standard error of mean SEM(±) and the critical difference (CD) were calculated at a 5% level of probability. The data have been depicted by suitable graphs and figures in the appropriate table.

The regression coefficient (R^2) was calculated by using SPSS 20.0 statistical package by following nonlinear multiple regression analysis. The R^2 is the most important measure for selecting the best equation to illustrate the drying curve equation. Furthermore, the reduced χ^2 (Chi square) as the mean square of the deviations between the experimental and calculated values for the models, and root mean square error (*RMSE*) analysis was used to determine the correlation fit. The higher values of R^2 and lowest values of χ^2 and *RMSE* provide the superior correlation [23].

$$\chi^2 = \sum_{i=1}{}^{N} \underline{(MR_{exp,i} - MR_{pre,i})^2} \quad (4)$$

$$N - n \quad (5)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2\right]^{1/2} \quad (6)$$

$$R^2 = [N\sum xy - \sum x \sum y \sqrt{[N\sum x^2 - (\sum x)^2][N\sum y^2 - (\sum y)^2]}]^2 \quad (7)$$

where χ^2 = Chi square; MR exp = experimental moisture ratio; MR pre= predicted moisture ratio; N = number of observations; n = number of constant; *RMSE* = root mean square error, and R^2= coefficient of determination.

3. Results and Discussion

3.1. Time Taken to Reach the Safe Moisture Content (8–10%)

There were significant differences among the drying methods and temperatures. In all the drying methods, the safe moisture content was 8–10% in dried chillies. Moisture content decreased with amplified drying time (Figure 2). In the two years of pooled data content, a similar pattern has been observed in time taken to reach safe moisture. Minimum time taken (480 min) for safe moisture content was recorded in T_7 (oven drying at 70 °C) followed by T_6 (oven drying at 65 °C) (540 min), with the maximum time taken (1260 min) to reach safe moisture content in T_1 (sun drying method) followed by T_2 (solar drying) (900 min). The oven drying system has proven to be beneficial in reducing the drying time. Similar results were also achieved by the research conducted by Wade et al. [24]. The hot air oven method took the least time, since the temperature of the oven was constant (70 °C). Similar trends were obtained in the observations of Gupta et al. [25]. Similarly, Carbonell et al. [26] also reported that the moisture content of dried chill was from 8% to 10%, which could slow down color loss. Moisture content <8% could accelerate pigment damage. A moisture content >11% leads to mold growth, and a moisture content <4% leads to unnecessary color loss. However, chilli usually should be dried to a moisture content of <13% in order to prevent potential aflatoxin production [27].

3.2. Color Values (L, a*, b*)*

Color parameters such as L*, a*, and b* were varied significantly as influenced by drying methods and temperatures (Table 2). During 2018–19, the highest L* value (25.40), a* value (33.91), and b* value (21.56) were shown in T_6 (oven drying at 65 °C). The lowest L* value (10.83), a* value (17.12), and b* value (9.27) were recorded in T_1 (sun drying method). In the year 2019–2020, the maximum L* value (23.69), a* value (30.36), and b* value (19.50) were recorded in T_6 (oven drying at 65 °C), whereas the minimum L* value (10.51), a* value (15.59), and b* value (9.63) were observed by T_1 sun drying. These results were in accordance with the findings of Wiriya et al. [28]. Using the sun drying method followed by drying at air temperatures of 50, 60, and 70 °C which lowered the value of the color of dried chilli. Although the delta E values were not listed in the table, they were found to be above one in almost all cases, signifying the reasonably visible darker exterior compared to the fresh samples [29]. The minimal color fall during the oven drying was indicative of the appropriateness of the method which may be proven to be safeguard nutraceutical foods [30]. However, the elevated color degradation in the sun-dried sample was attributable to pigment oxidation and decomposition. These were owing to the higher exposure to oxygen during intensive vaporization over chilli surface [31]. Total color difference (35.06) was found at its maximum in sun drying and at its minimum (11.82) in oven drying at 65 °C. Quite a few studies [32,33] also revealed maximum total color disparity in sun drying, though it was adverse in terms of other color attributes. This pigment oxidation and decomposition might be caused by higher exposure to oxygen as well as intensive vaporization from the pepper surface.

3.3. Texture (g)

In 2018–2019, treatment T_1 (sun drying) gave the maximum texture (1165.24 g). T_7 (oven drying at 70 °C), produced the minimum texture (755.78 g) (Table 3). In the second year, 2019–2020, the maximum texture (1196.38 g) was observed by T_1 (sun drying), whereas the minimum texture (723.31 g) was found in T_7 (oven drying at 70 °C). In the pooled data, the highest texture (1180.81 g) was observed in treatment T_1 (sun drying). The lowest texture (739.55 g) was recorded by T_7 (oven drying at 70 °C). The maximum firmness value was reached when samples were dried at 50 °C and 60 °C air drying. Temperatures above these values produced a decline in firmness. Drying temperature had a negative effect on this textural property, presenting a maximum decrease of 50% at 70 °C as compared to fresh samples. This loss in tissue rigidity could be explained by changes in the plant cell wall that occurred during processing at high temperatures [7,34,35]. During the drying process, the softening of the dehydrated peppers could partly be a result of turgor loss and solubilization of pectic substances in the cell wall and middle lamella, resulting in cell separation and collapse of the cell structure.

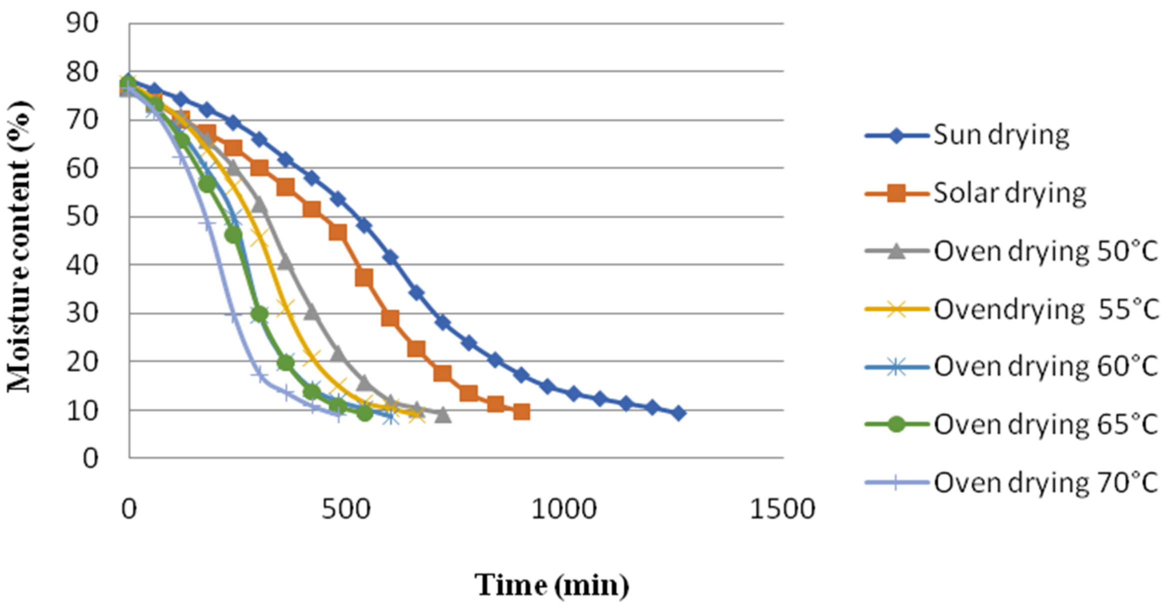

Figure 2. Effect of different drying methods and temperatures on time taken to reach safe moisture content (8–10%).

Table 2. Effect of different drying methods and temperatures on color values (L*, a*, and b*) of dry chilli.

Treatments	L			a			b		
	2018–2019	2019–2020	Pooled	2018–2019	2019–2020	Pooled	2018–2019	2019–2020	Pooled
Fresh chilli	29.64	28.42	29.03	43.58	41.28	42.43	24.23	23.78	24.00
Sun drying	10.83	10.51	10.67	17.12	15.59	16.36	9.27	9.63	9.45
Solar drying	14.37	13.90	14.13	21.74	18.94	20.34	12.66	12.39	12.53
Oven drying at 50 °C	17.21	16.11	16.66	24.26	22.43	23.35	15.54	14.44	14.99
Oven drying at 55 °C	19.54	18.12	18.83	26.56	24.17	25.37	17.08	15.95	16.52
Oven drying at 60 °C	21.37	19.86	20.62	28.98	26.43	27.71	18.79	17.46	18.12
Oven drying at 65 °C	25.40	23.69	24.55	33.91	30.36	32.14	21.56	19.50	20.53
Oven drying at 70 °C	23.50	21.57	22.54	31.09	28.53	29.81	20.42	18.53	19.47
SEM(±)	0.115	0.265	0.14	0.317	0.542	0.352	0.189	0.331	0.222
C.D $_{(0.05)}$	0.357	0.825	0.436	0.987	1.689	1.097	0.59	1.032	0.691

T_1: (Sun drying), T_2: (Solar drying), T_3: (Oven drying at 50 °C), T_4: (Oven drying at 55 °C), T_5: (Oven drying at 60 °C), T_6: (Oven drying at 65 °C), T_7: (Oven drying at 70 °C).

Table 3. Effect of different drying methods and temperatures on texture (g) and sensory score of pungency (1–9) of dry chilli.

Treatments	Texture (g)			Sensory Score of Pungency (1–9)		
	2018–2019	2019–2020	Pooled	2018–2019	2019–2020	Pooled
Fresh chilli	2818.39	2923.88	2871.13	6.86	6.76	6.81
Sun drying	1165.24	1196.38	1180.81	7.14	7.17	7.15
Solar drying	1047.22	1051.94	1038.58	7.31	7.24	7.27
Oven drying at 50 °C	1025.95	1006.26	1027.11	7.45	7.42	7.44
Oven drying at 55 °C	967.25	932.09	949.67	7.58	7.54	7.56
Oven drying at 60 °C	921.26	878.38	899.82	7.69	7.65	7.67
Oven drying at 65 °C	830.57	815.68	823.13	7.86	7.84	7.85
Oven drying at 70 °C	755.78	723.31	739.55	7.76	7.73	7.75
SEM(±)	9.966	8.773	7.742	0.003	0.001	0.002
C.D $_{(0.05)}$	31.048	27.332	24.119	0.011	0.004	0.006

T_1: (Sun drying), T_2: (Solar drying), T_3: (Oven drying at 50 °C), T_4: (Oven drying at 55 °C), T_5: (Oven drying at 60 °C), T_6: (Oven drying at 65 °C), T_7: (Oven drying at 70 °C).

3.4. Sensory Score of Pungency (1–9)

The maximum pungency score (7.86) has been recorded in T_6 (oven drying at 65 °C), while minimum pungency score (7.14) was observed in T_1 (sun drying method) in 2018–2019 (Table 3). The pungency score (7.84) was found to be at its maximum in T_6 (oven drying); however, the pungency score (7.17) was observed at its minimum in T_1 (sun drying method) in the next year, 2019–2020. In the pooled data, the maximum pungency score (7.85) was given in T_6 (oven drying at 65 °C), and the minimum pungency score (7.15) and (7.27) was found by T_1 (sun drying). The sensory score of pungency was significantly varied among different drying methods and temperatures. Daood et al. (1996) [36] also observed that the hotness of chilli varied appreciably and was high in hot air drying. This was in compliance with the observation of Apriyantono and Ames [37] and Elmore et al. [38]. Sun drying was the least liked sample on most attributes, while hot air oven drying received the highest liking scores on most attributes. The hot air oven sample contained a higher intensity of burnt chilli odor than the sun-dried samples. The formation of 2-acetyl furan, furfural, and 5-methylfurfural, which were generated during hot-air drying, might be accountable for the burnt attribute. A similar observation reported [39] that the capsaicin content and hotness were more accessible in hot air drying than in sun-dried drying. The sun drying sample showed the lowest scores in all qualities. This might be because of the over-exposure of the sun-dried samples to the air for a long time. The hotness attributes of chilli acknowledged by panelists were overall burning, burning on the tip of the tongue, stinging, numbing, and warming. A similar trend was recorded by Toontom et al. [40].

3.5. Ascorbic Acid (mg/100 g)

Different drying methods and temperatures varied significantly in ascorbic acid content in dried chilli samples (Table 4). In 2018–2019, T_3 (oven drying at 50 °C) gave a maximum of ascorbic acid (55.72 mg/100 g), whileT_1 (sun drying method) recorded a minimum of ascorbic acid (40.29 mg/100 g). In 2019–2020, the highest amount of ascorbic acid (56.39 mg/100 g) was found to be in T_3 (oven drying at 50 °C), whereas the minimum amount of ascorbic acid (41.24 mg/100 g) was recorded by T_1 (sun drying). Correspondingly, in the case of pooled data, the maximum amount of ascorbic acid (56.06 mg/100 g) was observed in T_3 (oven drying at 50 °C); however, the minimum ascorbic acid (40.77 mg/100 g) was recorded by T_1 (sun drying). The result agrees well with those of Vega-Galvez et al. [7] and Di Scala and Crapiste [11]. Ascorbic acid was degraded by elevated temperatures, and the degradation product (L dehydro ascorbic acid, DHAA) could contribute to Strecker degradation with amino acid, producing a browning pigment [41]. Not only does the high temperature of drying air influence the loss of ascorbic acid, but an elongated drying time can also introduce a major loss of ascorbic acid. The corresponding loss of ascorbic acid in sun drying was attributable to oxidation when the dried chilli was exposed directly to light and sun [42].

Table 4. Effect of different drying methods and temperatures on ascorbic acid (mg/100 g) and oleoresin content (%) of dry chilli.

Treatments	Ascorbic Acid (mg/100 g)			Oleoresin Content (%)		
	2018–2019	2019–2020	Pooled	2018–2019	2019–2020	Pooled
Fresh chilli	147.86	147.12	147.49	30.59	30.51	30.55
Sun drying	40.29	41.24	40.77	7.53	7.42	7.48
Solar drying	42.64	44.81	43.73	8.44	8.77	8.61
Oven drying at 50 °C	55.72	56.39	56.06	10.84	10.60	10.72
Oven drying at 55 °C	52.97	53.14	53.06	10.39	10.47	10.43
Oven drying at 60 °C	49.15	50.38	49.77	9.70	9.69	9.70
Oven drying at 65 °C	46.67	47.67	47.17	9.32	9.43	9.38
Oven drying at 70 °C	44.58	45.64	45.11	9.02	9.03	9.03
SEM(±)	0.291	0.347	0.255	0.189	0.121	0.118
C.D $_{(0.05)}$	0.906	1.082	0.795	0.588	0.376	0.369

T_1: (Sun drying), T_2: (Solar drying), T_3: (Oven drying at 50 °C), T_4: (Oven drying at 55 °C), T_5: (Oven drying at 60 °C), T_6: (Oven drying at 65 °C), T_7: (Oven drying at 70 °C).

3.6. Oleoresin Content (%)

Maximum oleoresin content (10.84%) was observed to be the highest in T_3 (oven drying at 50 °C), and the lowest oleoresin content (7.53%) was found to be in T_1 (sun drying) (Table 4) In the following year, maximum oleoresin content (10.60%) was found in T_3 (oven drying at 50 °C), and minimum oleoresin content (7.42%) was found in T_1

(sun drying). In the pooled data, oleoresin content (10.72%) was recorded at a maximum in T_3 (oven drying at 50 °C), and the minimum (7.48%) was shown by T_1 (sun drying method). Oleoresin content (%) was significantly influenced by different treatments. The less % of oleoresin in drying could be attributed to the sensitivity of oleoresin to continuous heating. These results were in line with the findings of Prasad [43]. Oven drying recorded the maximum oleoresin, which was considerably superior to the other reported methods of drying. The minimum content of oleoresin was recorded by sun drying. The lower % of oleoresin in sun drying could be attributed to the sensitivity of oleoresin to continuous heating. A similar trend was recorded by Gupta et al. [25]. Product quality was reduced significantly during sun drying and mechanical drying at 70 °C.Similar results were also observed by Maurya et al. [32]. The loss of total phenol compounds may possibly be caused by likely enzymatic processes during sun drying.

3.7. Mathematical Models

Mathematical relationships were found in the different drying methods and temperatures (Table 5). Models such as Lewis, Page, Modified Page, and Henderson and Pabis models were selected to fit the data. From the graphs showing a relationship between moisture and drying time, the values on mode of drying with constants k and coefficients a and n have been presented. The statistical parameters for the goodness of fit of the models, such as R^2, χ^2, and $RMSE$ were calculated using equations. The highest R^2 value and the lowest χ^2 and $RMSE$ values indicated better goodness of fit. The two years of pooled data presented in Table 4 revealed that the maximum R^2 (0.9835) was found in both Page and Modified Page models, indicating similar values of drying method and temperature at 65 °C, which was the highest among all models in all drying temperatures. R^2 significantly ranged from 0.924 to 0.9835, whereas the least R^2 (0.924) was shown in the Henderson and Pabis model. The same pattern has been registered in two-year and pooled data. However, the lowest χ^2 and $RMSE$ (0.000818 and 0.027261) were recorded by the Page model, and then in the Modified Page model (0.000832 and 0.027461), while the highest χ^2, and $RMSE$, (0.045256 and 0.205647) and (0.042182 and 0.19663), were produced in the Henderson and Pabis as well as Lewis models. The ranges of χ^2 (0.045256 and 0.042182) and $RMSE$ (0.205647 and 0.19663) were the same in all the mathematical models for different drying methods and temperatures. A similar trend was recorded by Gupta et al. while establishing the relationship through mathematical models [25]. The Page Model was found to be the most appropriate one out of all the models corresponding to the drying behavior of chillies under different drying techniques. These findings were line with Fudholi et al. [44]. The Page drying model exhibited the highest value of R^2 and the lowest values of $RMSE$ compared with the Henderson and Pabis model. Similar results were recorded by Arora [2]. The Page model fitted best with the experimental data for its better values of R^2, while standard errors were less than 0.05. Niu et al. (2021) [45] also observed similar findings derived from the criteria of the highest R^2 and the lowest $RMSE$; Page's model was selected as the most appropriate model to characterize the hot air and vacuum drying behavior for red peppers.

Table 5. Mathematical modelsfor different drying methods and temperatures of dry chilli.

Drying Method	Model	k	n	R^2	χ^2	*RMSE*	a
Sun drying	Lewis	0.002		0.968	0.035271	0.183265	
	page	0.000020073	1.627	0.9775	0.001781	0.040624	
	Modified page	0.001294	1.627	0.9775	0.00178	0.040619	
	Henderson & Pabis	0.002		0.968	0.019716	0.13674	1.44725
Solar drying	Lewis	0.002		0.924	0.024381	0.151016	
	page	0.0000641775	1.538	0.9615	0.003241	0.054975	
	Modified page	0.001571	1.538	0.9615	0.003241	0.054975	
	Henderson & Pabis	0.002		0.924	0.045256	0.205647	1.533675
Oven drying at 50 °C	Lewis	0.003		0.9615	0.029898	0.166107	
	page	0.00001985	1.769	0.9775	0.001648	0.038947	
	Modified page	0.002188	1.769	0.9775	0.001648	0.038948	
	Henderson &Pabis	0.003		0.9615	0.044506	0.202443	1.572445
Oven drying at 55 °C	Lewis	0.004		0.964	0.042182	0.19663	
	page	0.0000242283	1.7765	0.982	0.001605	0.038349	
	Modified page	0.002498	1.7765	0.982	0.00162	0.038534	
	Henderson & Pabis	0.004		0.964	0.038484	0.187816	1.555825
Oven drying at 60 °C	Lewis	0.004		0.9645	0.026134	0.154122	
	page	0.0000376625	1.7455	0.9755	0.002667	0.048719	
	Modified page	0.0028777	1.7455	0.9755	0.002668	0.048734	
	Henderson & Pabis	0.004		0.9645	0.032407	0.170892	1.481505
Oven drying at 65 °C	Lewis	0.0045		0.9705	0.032362	0.165709	
	page	0.00006007625	1.7815	0.9905	0.000818	0.027261	
	Modified page	0.0030645	1.7815	0.9905	0.000832	0.027461	
	Henderson & Pabis	0.0045		0.9705	0.041545	0.191818	1.531435
Oven drying at 70 °C	Lewis	0.005		0.9735	0.021161	0.136996	
	page	0.0000530275	1.7595	0.9835	0.001841	0.040435	
	Modified page	0.0036469	1.7595	0.9835	0.001965	0.041793	
	Henderson & Pabis	0.005		0.9735	0.026833	0.154369	1.424835

T_1: (Sun drying), T_2: (Solar drying), T_3: (Oven drying at 50 °C), T_4: (Oven drying at 55 °C), T_5: (Oven drying at 60 °C), T_6: (Oven drying at 65 °C), T_7: (Oven drying at 70 °C).

4. Conclusions

Chilli was dried using different drying methods such as sun drying, solar drying, and oven drying. In oven drying, different temperatures were used including 50, 55, 60, 65, and 70 °C. The minimum time taken (480 min) to reach safe moisture content was recorded using oven drying at 70 °C, whereas maximum values in color components L* value (24.55), a* value (32.14), and b* value (20.53) and pungency score (7.85) were recorded using oven drying at 65 °C. However, the highest texture (1180.81) was observed in T_1 (sun drying). The maximum amount of ascorbic acid (56.06 mg/100 g) and oleoresin content (10.72) were found using oven drying at 50 °C, Mathematical relationships were found in different drying methods and temperatures, and the maximum R^2 value (0.9835) was found in both the Page and Modified Page models with similar values of drying method and temperature at 65 °C. However, the lowest χ^2 and *RMSE* values (0.000818 and 0.027261) were recorded with the Page model.

Oven drying is the best drying method so far, as the quality aspects are taken into account due to faster elimination of moisture from the sample, retaining good color, pungency, ascorbic acid, and oleoresin content with minimum changes in surface texture of dry chilli, while there are poor color quality, low pungency, less ascorbic acid and less oleoresin in sun-dried chilli. Sun drying is cheaper, with poor-quality end products, and oven drying is cost-effective, with good-quality dried chilli as well. as far as the quality is concerned, solar drying is comparatively better than sun drying and more economically affordable than oven drying. In addition, as solar drying is performed in a covered condition, compared to open sun drying; thus, it is also safe from many environmental and pest hazards. Taking all these perspectives collectively, we may recommend the solar drying method for chilli as safe, especially where oven drying is not possible. It may be advocated not only for the use of dried red chilli as a spice for offering taste, color, pungency, and flavor to cooked food but also for its possible use in preparing pharmaceutical products with ample biomedical applications.

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