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Study of drying characteristics of coriander leaves dried under fluidized bed dryer using different mathematical models

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Abstract
The present study aimed to examine the drying kinetics of coriander leaves in a fluidized-bed dryer, using fresh leaves procured from the local market in Meerut. Dried 500 gm batches of control and blanched leaves at a constant air velocity of 2 m/s across temperatures of 40 °C, 50 °C, and 60 °C and their quality evaluation during storage period the dried samples sealed on LDPE pouches after drying and the untreated sample was taken as Control sample. The aim of this study was to determine the drying kinetic of the sample control and blanched were evaluated by using standard procedures. Consistent with existing literature on coriander leaf drying moisture removal occurred exclusively in the falling-rate period with no constant-rate phase observed. This indicates that internal moisture diffusion governed the drying process as is typical for thin leafy materials with limited surface moisture fitting two commonly applied drying models the Lewis model and the Page model to the experimental data revealed that the Lewis model provided a superior fit especially for blanched leaves dried in the fluidized-bed setup. Blanching likely modifies the leaf structure enhancing moisture diffusion and making the Lewis model more appropriate for predicting drying behaviour in these conditions. The physico chemical properties of control and blanched samples were analyzed just after drying.

Keywords: Drying kinetics, coriander leaves, physico-chemical, fluidized bed dryer

1. Introduction

Coriander (*Coriandrum sativum* L.) also known as cilantro or dhania, is an annual herb of the Apiaceae (formerly Umbelliferae) family. The plant exhibits delicate, feathery leaves, a thin hollow stem, and umbels of small pink or white flowers. Its entire structure—from roots to seeds is edible and utilized for various purposes. Coriander leaves are a reservoir of bioactive compounds including flavonoids, polyphenols, essential oils, and minerals. Studies using high-performance liquid chromatography-mass spectrometry (HPLC-MS) have identified phenolic compounds such as caffeoylquinic acids, feruloylquinic acids, and rutin in coriander leaves and seeds [5]. These compounds are responsible for antioxidant, antimicrobial, anti-inflammatory, and other therapeutic effects. The leaves are particularly rich in vitamin C and carotenoids, which act as natural antioxidants and help in strengthening the immune system. Drying is a time-tested method of food preservation aimed at reducing the water activity of produce to inhibit microbial growth and enzymatic reactions. It enhances the shelf life of leafy vegetables while making them easier to handle, package, and store [7]. Drying reduces volume and weight, which is advantageous for transportation and storage logistics. Advanced drying models have been developed to simulate and optimize the drying behaviour of agricultural produce. These models assist in understanding moisture transfer mechanisms, predicting drying time, and improving energy efficiency [12]. Emphasized that mathematical modeling can help optimize drying parameters to maintain product quality while ensuring energy efficiency. Drying prolongs the shelf life of coriander leaves, making them available throughout the year because it reduces microbiological activity. A lack of knowledge and literature regarding the drying behaviour of coriander leaves is the reason this particular issue was chosen to evaluate the safe storage moisture level. Dehydration makes the dried leaves easier to use in locations where they are unavailable. Dehydrated vegetables are more convenient to use and have a longer shelf life than fresh vegetables.

To improve menu diversity and save waste, labour, and storage space, green leafy vegetables are incorporated into daily diets to break up the monotony of the meals.

2. Materials and Methods

This chapter covers the theory with the materials used and the methods adopted to carry out the experiment on drying of coriander leaves using fluidized bed drying methods. Procedure was carried out in the Argo Processing Centre at College of Post Harvest Technology and Food Processing, Sardar Vallabhbhai Patel University of Agriculture and Technology ModiPuram Meerut. The detailed procedure of sample preparation experimental plan, drying methods and quality analysis are also presented. The quality degradation kinetics modelling and statistical analysis methods are also described.

2.1 Raw material and sample preparation

The fresh coriander leaves used for drying was bought from local market in Meerut. The insect infected, discoloured, wilted and decayed leaves were discarded during sorting. The stalks of the coriander leaves were detached from the main branches. Leaves were cut into 1.5±0.5 cm length using stainless steel knife. The drying experiments were conducted in the laboratory of college of post-harvest and food technology Sardar Vallabhbhai Patel university of agriculture ModiPuram Meerut.

2.2 Experimental setup

The experimental setup comprised a laboratory-scale fluidized bed dryer and a hot air oven for conducting drying and pre-treatment processes. Equipment such as a precision electronic balance, temperature-controlled water bath, and air circulation systems were utilized to ensure uniform processing and accurate measurement. These instruments enabled controlled drying conditions and consistent data acquisition for evaluating the drying behaviour and quality of coriander leaves.

2.3 Fluidized bed dryer

A laboratory-scale fluidized bed dryer (Sherwood Scientific Ltd., Cambridge, England) which consists of compact bench top unit (with heater and blower), filter bag, temperature controller, centrifuge with sealed tub assembly. This compact benchtop unit uses a powerful air delivery system and heater to rapidly remove the moisture.

2.4 Process for the development of green coriander leaves powder

The preparation of green coriander leaves powder involved a series of carefully controlled steps to ensure quality and shelf stability. Initially, fresh coriander leaves were sorted and cleaned to remove dirt and impurities, followed by cutting into uniform sizes to facilitate even drying. The pre-treated leaves were then subjected to drying using a fluidized bed dryer, which efficiently removed moisture while preserving color and aroma. The dried leaves were packed in LDPE (Low-Density Polyethylene) bags to protect them from environmental exposure during storage. Subsequent quality analysis was performed at regular intervals, and the data was used to study the kinetics of quality degradation during storage, aiding in determining optimal storage conditions and shelf life.

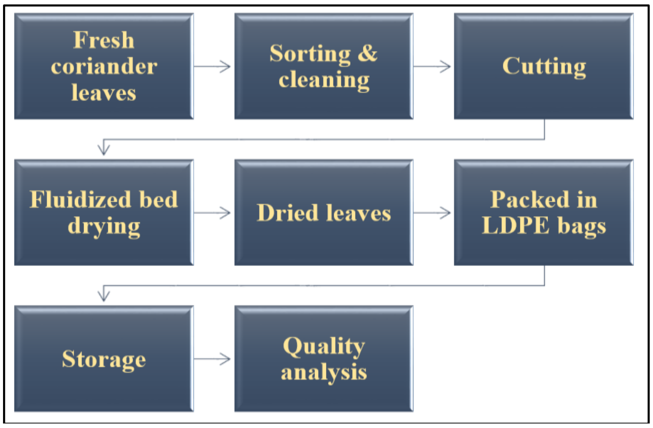

Fig 1: Process Flow Diagram for Green Coriander Leaf Powder Preparation

2.5 Determination of drying parameters

To evaluate the drying behaviour and quality retention of coriander leaves, several drying parameters were systematically measured. These included the moisture ratio, drying rate, and rehydration ratio, which provide insights into moisture removal efficiency and product recovery potential. In addition, moisture content was regularly assessed to monitor the drying progression. These parameters together help optimize drying conditions and ensure the development of a high-quality dehydrated product.

2.6 Determination of moisture ratio

Moisture ratios (MR) of green coriander leave samples in each dryer were calculated by using the following equation [11].

$$MR\ (\%) = \frac{w_t - w_e}{w_i - w_e} * 100$$

where, w_t. = Moisture content at time t (db.), gm; w_i = Moisture content at time zero (db.), gm; w_e. = Moisture content in equilibrium state, gm

2.8 Determination of drying rate

The moisture content data recorded during experiments were analyzed to determine the moisture lost from the sample of coriander leaves in particular time interval. The drying rates of samples were calculated by following mass balance equation [3].

$$DR = \frac{WML(kg)}{dT(min) \times DM}$$

Where,
DR = Drying rate at time θ
WML = Initial weight of sample-Weight of sample after time θ
DM = dry matter, kg.

3. Results and Discussion

3.1 Effect of temperature on moisture content

Control sample and blanched sample were dried using a fluidised bed dryer. During drying the moisture content in the sample dropped rapidly over time. Higher drying air temperatures led to a faster reduction in moisture content which means the drying process was quicker when the air was hotter. The reduction in moisture content with respect to time of coriander sample dried under fluidised bed drying are shown in fig. 2 and 3. The change in moisture content of coriander sample with elapsed drying time at each of drying temperature 40 °C, 50 °C and 60 °C at air velocity of 2 m/s with two treatments. The final moisture content was found 6.18% for control sample and 6.2% for blanched at 40 °C. Both type samples had 6.2% moisture content at 50 °C. Similarly, the final moisture content was found 6.1% for control sample and 6.3% for blanched sample at 60 °C. This shows that control samples tend to dry a bit faster than blanched sample. Overall drying time was shortest at 60 °C and longest at 40 °C. The drying curves confirmed that increasing air temperature reduces the time needed to reach low moisture levels. Pre-treatment like blanching affected the drying rate slightly making the process a bit slower for blanched sample at lower temperatures. The same pattern of findings was previously reported by [15] in their study of coriander sample and stems, as well as by [14] in their work on basil sample.

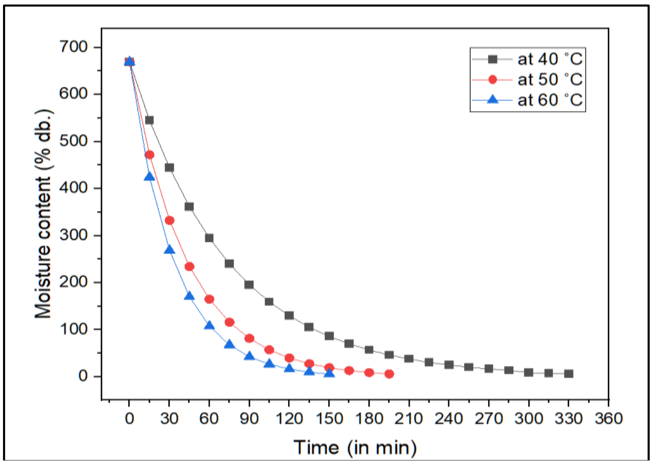

Fig 2: Moisture content of control sample

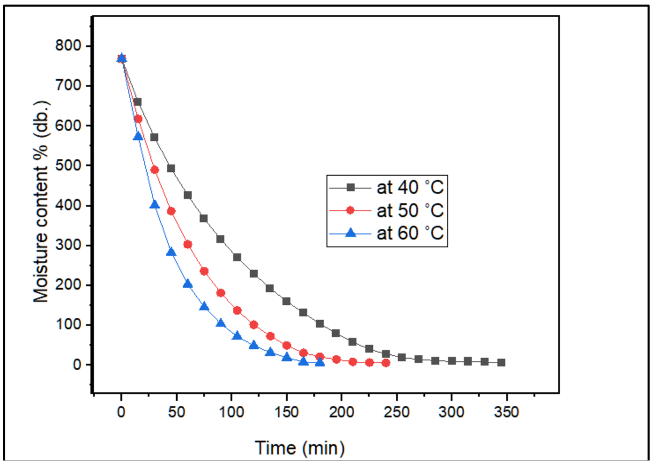

Fig 3: Effect on moisture content of Blanched sample

3.2 Effect of temperature on moisture ratio of coriander sample

The moisture ratio (MR) of coriander sample both control and blanched sample declines exponentially over time at temperatures of 40 °C, 50 °C, and 60 °C (as shown in Figures 4 and 5). The moisture Ratio of control sample decrease from 1.0 to 0.009 in 330 minutes, while blanched sample take slightly longer time 345 minutes to reach MR ≈ 0.008 at 40 °C. The drying speed increase at 50 °C and the moisture ratio of control sample reach ≈ 0.009 in 195 minutes and the moisture ratio of blanched sample reach ≈ 0.007 in 240 minutes. At 60 °C drying is fastest control sample achieve MR ≈ 0.009 in 150 minutes and blanched sample in 180 minutes. The smooth, exponential drop in MR indicates diffusion-controlled moisture movement and higher temperatures accelerate moisture loss by enhancing heat transfer into the sample [4]. Our results show that hotter drying air makes coriander sample dry much faster. This matches findings by [15] on coriander, [10] on drumstick sample, and [9] on lettuce.

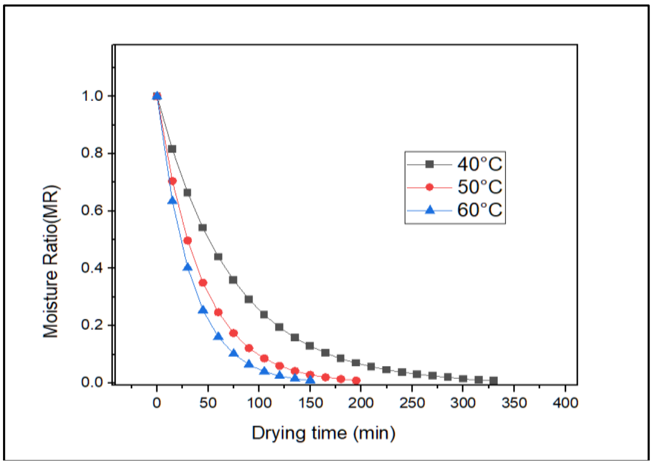

Fig 4: Moisture ratio curve of Control sample

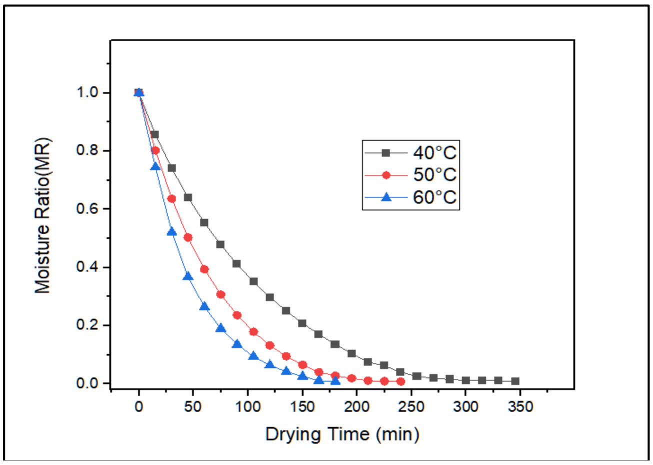

Fig 5: Moisture ratio curve of blanched sample

3.3 Effect of temperature on drying rate of coriander sample

The drying rate for coriander sample was calculated by determining the change in moisture content over a set time interval and expressing it in grams of evaporated water per gram of dry matter per minute (g w/g dm-min). Figures 6 and 7 presented how the drying rate varies with moisture content under different drying air temperatures and pre-treatments in a fluidized-bed dryer. Initially the drying rate was high then it steadily declined following the classic pattern of drying curves. For control sample the maximum drying rates during the initial drying phase were found 6.45, 10.26, and 12.74 g w/g dm-min at air temperatures of 40 °C, 50 °C, and 60 °C, respectively while the value were found 5.01, 6.96, and 9.01 g w/g dm-min for blanched sample at the same temperatures, these rates steadily decreased over time. The lower drying rate in blanched sample as compared to control sample is attributed to the effects of blanching . The drying process was found to be diffusion-controlled as evidenced by its temperature dependence higher temperatures led to faster moisture removal. No constant-rate drying period was observed the entire process occurred in the falling-rate period, indicating that evaporation slowed continuously as drying progressed. These findings match earlier work by [2] on apricots, [8] on spinach sample, [6] on various herbal sample, and [1] on spinach sample.

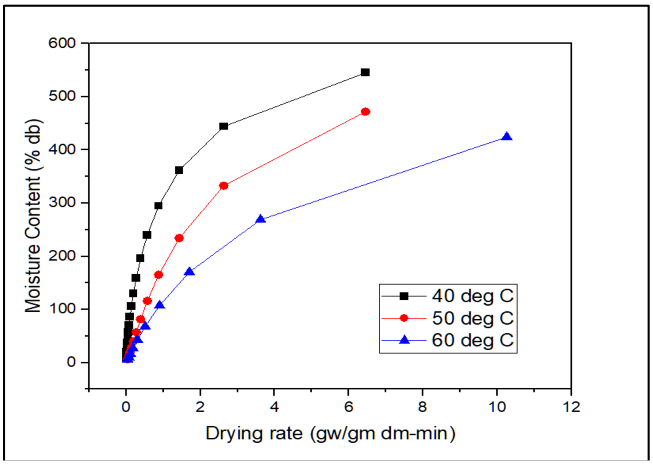

Fig 6: Drying rate curve of control sample.

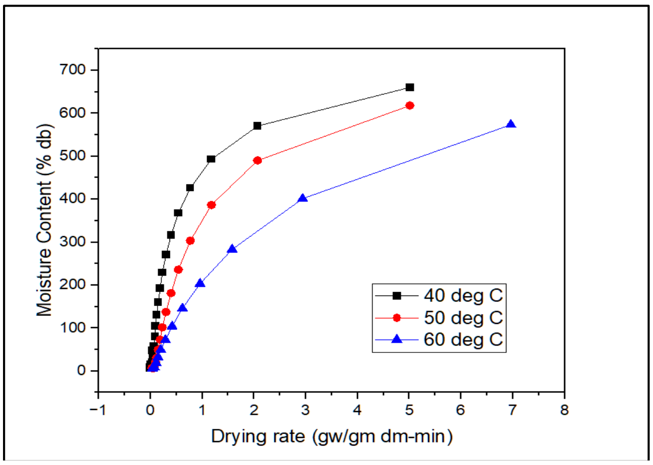

Fig 7: Drying rate curve of blanched sample.

4. Mathematical Modeling

Two different thin layer mathematical models were evaluated Many thin layer drying models of agricultural products are mainly empirical in nature, because of non-isotropic and non-homogenous nature of the agricultural products along with the irregular shape and the changes in their shape during time. Always authors propose quite simple models to simulate the drying curves of food that can provide adequate representation of experimental results although the parameters of these models lack of physical sense. The most simplified model was found to be fitted to exponential characteristics [13].

The moisture ratio data of coriander sample dried at various air temperatures and treatment were fitted into two thin layer drying models i.e. Lewis model and page model between these models, the best model suitable to fit the data was selected on basis of highest values of coefficient of determination (R^2). The statistical parameters for these models used for fluidised bed dried coriander sample have been presented in Table 3.1 . The best fitted model describes the drying kinetics of coriander identified in accordance with the highest value of R^2. From the model analysis results, it was found that the Lewis model (highest value of R^2) Fit for the coriander sample drying .It identified as the best suitable model to expressed the drying behaviour of coriander sample.

Table 1: Values for model constant in fluidised bed drying of coriander sample

Treatments	Temperature	Lewis model		Page Model		
		K	R^2	K	N	R^2
Control	40 °C	0.2102	0.9988	0.2071	0.4622	0.539
	50 °C	0.3579	0.9988	0.3766	0.3923	0.5131
	60 °C	0.4635	0.9999	0.4778	0.3663	0.5196
Blanched	40 °C	0.2234	0.9792	0.3609	0.1139	0.818
	50 °C	0.3702	0.9913	0.4117	0.3941	0.5856
	60 °C	0.3959	0.9861	0.3596	0.3911	0.4577

5. Conclusion

Samples took 330 to 345 min to dry under fluidised bed drying to bring the initial moisture content (669.23% to 769.6%) to final moisture content in the range of 6.18 to 6.20 per cent (db.) at 40 °C. The coriander samples (control and blanched) dried quickly in a fluidized-bed dryer with hotter air making the process much faster fastest at 60 °C and slowest at 40 °C. The control leaves consistently dried a bit faster than the blanched ones. The moisture ratio dropped exponentially over time with faster drying at higher temperatures control samples reached ~0.009 MR in 150 min at 60 °C, compared to 330 min at 40 °C. This indicates that moisture movement is diffusion controlled and that increasing air temperature significantly accelerates drying of coriander leaves. Drying of coriander leaves took place in falling rate period was completely absent in fluidised bed drying experiment. Drying time of coriander was shortest at 60 °C and longest at 40 °C for both the samples. The coriander control and blanched samples dried in a fluidized-bed dryer exhibited peak initial drying rates at 60 °C of 12.74 g w/g dm-min and 9.01 g w/g dm-min, respectively, with rates declining continuously under falling-rate period conditions. The moisture ratio data from coriander samples, dried under varied air temperatures and treatments, were fitted to Lewis and Page thin-layer models, with Lewis providing the superior fit based on the highest coefficient of determination (R^2). This indicates that Lewis's simple exponential model most accurately captures the drying kinetics of coriander leaves in this fluidized-bed drying scenario.

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