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Amgoth Venkanna
Department of Processing and Food Engineering, College of Technology and Engineering Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, India

PS Champawat
Department of Processing and Food Engineering, College of Technology and Engineering Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, India

SK Jain
Department of Processing and Food Engineering, College of Technology and Engineering Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, India

Correspondence
Amgoth Venkanna
Department of Processing and Food Engineering, College of Technology and Engineering Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, India

Study on drying kinetics of coriander leaves using different drying techniques

Amgoth Venkanna, PS Champawat and SK Jain

Abstract
Coriander (*Coriandrum sativum*) is a herbaceous annual plant with fan-shaped feathery leaves and clusters of pale mauve flowers. Its aromatic leaves are used as a herb in many oriental dishes and soups, but in terms of international trade, it is mainly grown for the round, aromatic seeds, which are used as a spice. In the present study, coriander leaves which were procured from the local market of Udaipur were dried by using tray dryer and fluidized bed dryer. Also, the drying kinetics of coriander leaves were compared. The fresh and blanched leaves weighing 100 g were dried in tray dryer and fluidized bed dryer at air temperature of 45, 55 and 65 ºC at fixed air velocity of 2m/s. The results showed that drying of coriander leaves took place in falling rate period and constant rate period was absent in both tray drying and fluidized bed drying experiments.

Keywords: *Drying* kinetics, constant rate period, falling rate period and drying rate

Introduction
Coriander has strong fragrance. It is highly reputed ayurvedic medicinal plant. This plant is highly aromatic and has multiple uses in food. Plants have played a critical role in maintaining human health and civilizing the quality of human life for thousands of years (Dhankar *et al.* 2011) [5]. All parts of plant are edible, fresh leaves can be used for garnishing and are common ingredient in many foods like chutneys and salads. In India, fresh Coriander is abundantly available during winters from December to March but has very short shelf life even under refrigerated conditions. This leads to a marked scarcity in availability and a sharp rise in price in the lean period. During peak period, most of the crop is lost/wasted due to lack of proper post-harvest processing techniques. The fresh green coriander leaves if properly dried, packaged and stored may help in increasing its availability during lean periods.
An important observation about the coriander is the moisture content, which favors both its microbial and nutritional degradation, requiring immediate processing in order to increase its shelf life and provide the final product with quality. Among the techniques used to maintain post-harvest quality of herbs, drying is used to prevent deterioration and loss in commercial value. The technique causes the transformation of the product, adding value to it and originating a new option in the market (Akpinar *et al.* 2003) [2].
However, the use of such a technique without any previous knowledge and process control, such as temperature, air velocity and initial moisture that controls the drying process, can lead to complete nutritional and sensorial degradation of agricultural products submitted to the technique (Varnalis *et al*. 2001) [11]. Hence, to enhance the shelf life of green leafy vegetables, to augment the availability throughout the year and to create convenience to the users, research was undertaken to study the drying kinetics of coriander leaves by using convective air drying, fluidized bed drying, open sun drying and shade drying.

Materials and Methods
The present investigation was carried out in the Department of Processing and Food Engineering, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur. The flow chart for drying of coriander leaves is shown in Fig.1.

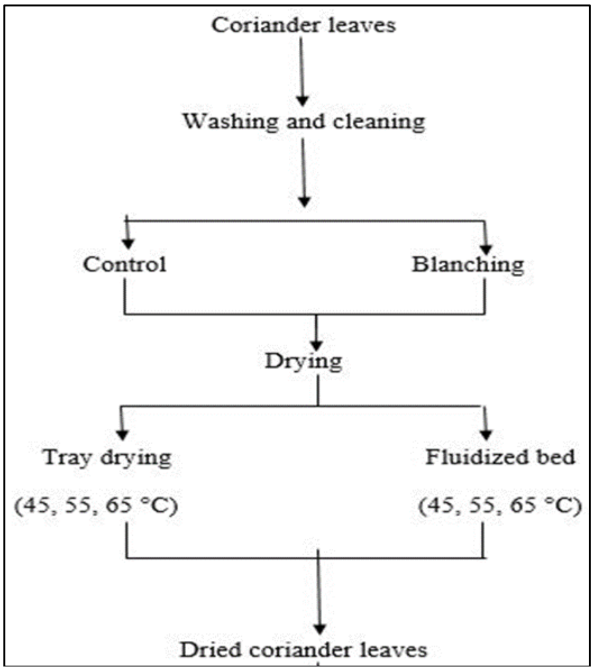

Fig 1: Flow chart for drying of coriander leaves

Preparation of sample

The fresh coriander leaves were procured from the local market of Udaipur, Rajasthan for this investigation. Insect infested, ruined, discolored, decayed, and wilted leaves were discarded before washing the leaves. The stalks of the leaves were cut from the main branches and the leaves were washed thoroughly three to four times with tap water to remove all foreign matter such as dust, dirt, chaff. After washing, leaves were spread on tissue paper to remove surface moisture. The residue moisture was evaporated at room temperature; these leaves were used for further study.
Sorted, cleaned and washed leaves were subjected to following treatments before drying;

1. P_1 – Control (without pre-treatment)
2. P_2 – Blanching: Cleaned coriander leaves were tied in a muslin cloth and kept in boiling water (90 ºC) for 2 minute and cooled immediately under running tap water

The initial moisture content of coriander leaves was determined by oven drying method. The two drying methods adopted for the present investigation were tray drying and fluidized bed drying. About 100 g of unblanched and blanched coriander leaves were taken and dried in tray dryer and fluidized bed dryer available in Department of Processing and Food Engineering, College of Technology and Engineering, Udaipur. The air flow rate was kept constant as 2 m/s. The samples were weighed at varying intervals till the required moisture content was achieved. The experimental set up of tray dryer and fluidized bed dryer is shown in Fig.2 & Fig.3.

Fig 2: Experimental tray dryer

Fig 3: Experimental fluidized bed dryer

The open sun drying experiments were conducted on the roof of the building of Processing and Food Engineering Department of College of Technology and Engineering, Udaipur. Drying was started at 9 a.m. in the morning. The site was selected in view of availability of adequate and unobstructed solar energy. The leaves were placed on iron tray. The trays were placed in direct sunlight on a roof away from animals, traffic and dust and turned occasionally to ensure even drying. The leaves were brought indoor at nights as the temperature during night falls down.
In shade drying also, leaves were spread on iron trays but instead of keeping them on the roof the leaves were kept inside the room. The room selected for shade drying was well ventilated. Natural current of air was used for shadow drying the leaves.

Drying Characteristics

Moisture content

The reduction in moisture content of coriander leaves was recorded at an interval of 5 min for first 30 min, then interval of 10 min for next 30 min, 15 min interval for next 1 hour and after that, every 30 min from next hour time till the end of drying process. The moisture content was calculated by using the following equation;

$$\text{Moisture content (per cent db)} = \frac{W_1\text{-}W_2}{W_2} \times 100 \; \ldots (1)$$

Where,
W_1 = Initial mass of the sample, g
W_2 = Final mass of the sample, g

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:

$$R = \frac{\text{WML(Kg)}}{\text{Time interval(min)} \times \text{DM}} \qquad \ldots(2)$$

Where,
R = Drying rate at time θ
WML = Initial weight of sample – Weight of sample after time θ
DM = dry matter, kg

Moisture ratio

The moisture ratio was calculated by using the following equation;

$$\text{Moisture ratio} = \frac{M\text{-}M_e}{M_0 - M_e} \quad \dots (3)$$

Where,
M = Moisture content at any specified time t (per cent db)
M_e = Equilibrium moisture content (per cent db)
M_0 = Initial moisture content (per cent db)
M_e in comparison to M_0 and M is very small, hence M_e can be neglected and moisture ratio can be presented in simplified form (Doymaz, 2004) [6].

$$MR = \frac{M}{M_0} \quad \dots (4)$$

Results and Discussion

This chapter deals with the results of the investigation carried out on different drying methods for coriander leaves. The effect of process variables on drying of Coriander leaves has been presented and discussed.

Initial Moisture Content

The initial moisture content of fresh coriander and blanched leaves were determined by oven drying method using Eq.1. The average initial moisture content of fresh coriander leaves and blanched leaves was found as 700.00 per cent (db) and 733.33 per cent (db) respectively.

Tray drying

Effect of temperature and pre-treatment on drying rate curves of coriander leaves

The drying rate for the coriander leaves was estimated from the difference in its moisture loss in a known time interval and expressed as g of moisture evaporated per g of dry matter-min. The drying rate as a function of moisture content at different drying air temperature for coriander leaves with treatment in tray dryer is shown in Fig. 4 and Fig.5. It can be seen that initially the drying rate was more and subsequently it reduced with drying time. It can also be seen that they follow typical drying rate curves. The maximum drying rate for control sample was observed at initial stage of drying as 0.1086, 0.1249 and 0.1517 g-water/ g-DM-min and for blanched sample 0.0798, 0.1028 and 0.1242 g-water/ g-DM-min for 45, 55 and 65 ºC of air temperature respectively. These drying rates continuously decreased with respect to time.

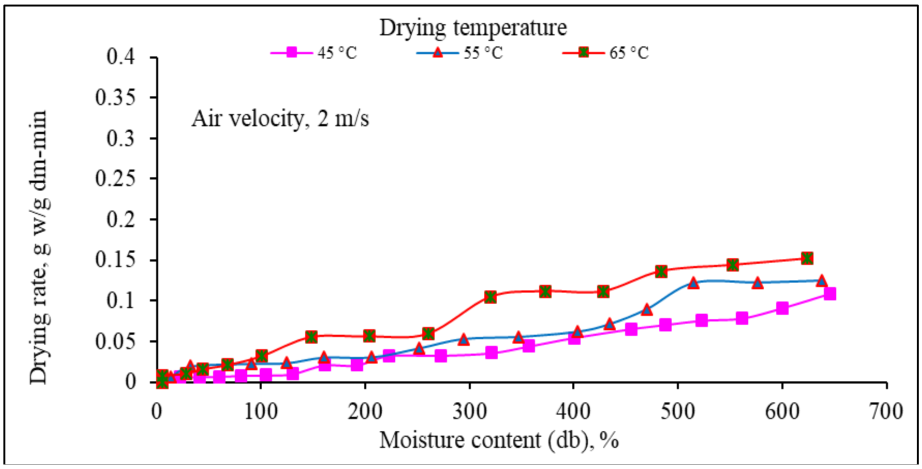

Fig 4: Drying rate curves of coriander leaves obtained at various air temperatures in tray drying

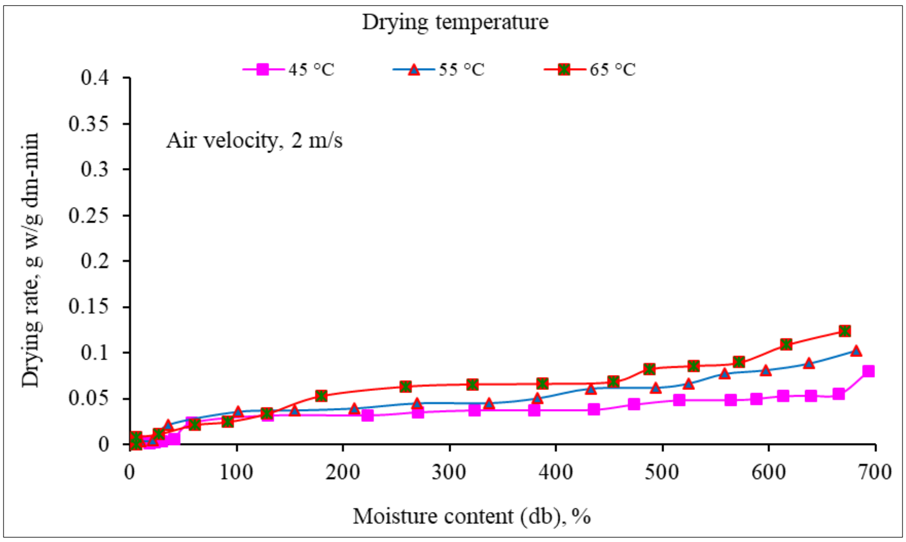

Fig 5: Drying rate curves of blanched coriander leaves obtained at various air temperatures in tray drying

The total drying time taken for drying coriander leaves in tray dryer at various temperatures for control and blanched samples were shown in Table 1.

Table 1: Drying time for coriander leaves in tray dryer

Treatment	Drying Air temperature (˚C)	Drying Time (min)
Control	45	360
	55	240
	65	180
Blanched	45	390
	55	270
	65	210

Drying rate of control and blanched sample was found to be different at same temperature because blanching decreased drying rate and consequently drying time has got increased. This behavior can be attributed to the excess of moisture present and modifications in the texture of the sample, by blanching which has become pasty. Similar reports have been supported by various researchers, e.g. Ahmed *et al*., (2001) [1], Silva *et al*., (2008) [10] for drying kinetics of coriander leaves.

From the observation it can be seen that, constant rate-drying period was not found in drying curves. The entire drying process took place in the falling rate period; the curves typically demonstrated smooth diffusion controlled drying behavior under all drying temperatures. Moreover, an important influence of air drying temperature on drying rate could be observed in these curves. It is obvious from these curves that the higher the drying temperature, the greater the drying rate, so the highest values of drying rate were obtained during the experiment at 65ºC. These results are similar to the earlier studies outcomes of different vegetables (Akpinar, 2005; Doymaz, 2004; Doymaz, 2007; Kadam *et al*., 2011) [3, 6, 7, 8].

Effect of temperature and pre-treatment on moisture ratio for coriander leaves

The initial moisture content was not same for all the drying experiments because of blanching treatment. Hence, the drying curves were normalized by converting the moisture content to moisture ratio (MR). The change in moisture ratio with respect to time for different drying temperatures for both blanched and control Coriander leaves is presented in terms of moisture ratio (MR) versus time graphs shown in Fig.6 and Fig. 7.

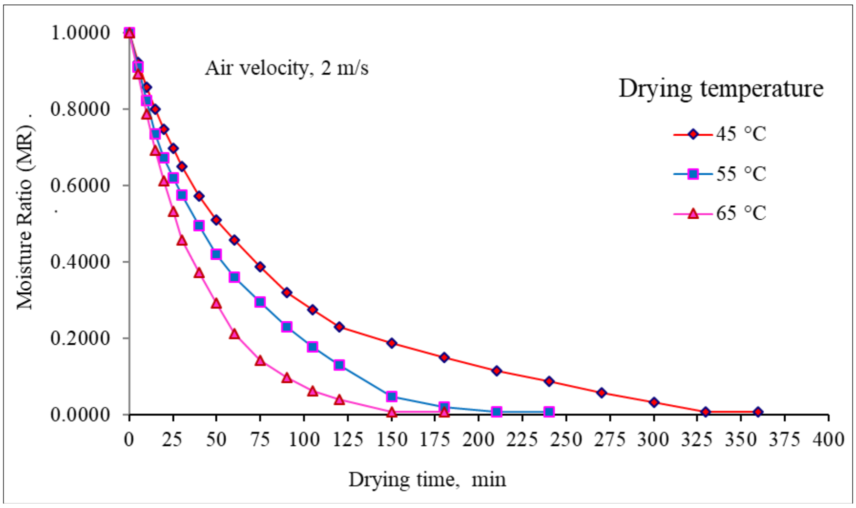

Fig 6: Moisture ratio curve of Coriander leaves at various temperatures in tray drying

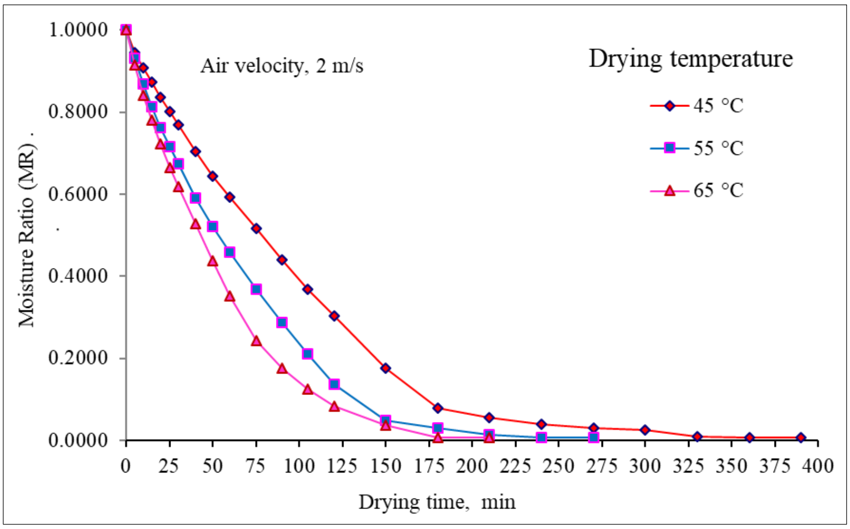

Fig 7: Moisture ratio curve of blanched Coriander leaves at various temperatures in tray drying

From the Fig. 6 and Fig. 7, it can be seen that the moisture ratio of tray dried coriander leaves dried at 45 ºC varied from 1.0 to 0.008 and from 1.0 to 0.008 at 360 and 390 min for control and blanched sample respectively, whereas at 55 ºC the moisture ratio was varied from 1.0 to 0.008 and from 1.0 to 0.008 at 240 and 270 min for control and blanched sample respectively. At 65 ºC the moisture ratio was varied from 1.0 to 0.008 and from 1.0 to 0.007 at 180 and 210 min for control and blanched sample. The variation might be due to pre-treatment. Also, from the Fig.6 and Fig.7, it can be seen that the moisture ratio reduced exponentially as the drying time increased. Continuous decrease in moisture ratio indicates that diffusion has governed the internal mass transfer. A higher drying air temperature decreased the moisture ratio faster due to the increase in air heat supply rate to the leaves and the acceleration of moisture migration. Experimental results showed that drying air temperature is effective parameter for the drying of coriander leaves. These results were in good agreement with earlier research by Silva *et al.*, (2008) [10] for coriander leaves and stems.

Fluidized Bed Drying
The total drying time taken for drying coriander leaves in fluidized bed dryer at various temperatures for control and blanched samples were shown in Table 2.

Table 2: Drying time for coriander leaves in fluidized bed dryer

Treatment	Drying Air temperature (˚C)	Drying Time (min)
Control	45	270
	55	90
	65	60
Blanched	45	270
	55	180
	65	150

Effect of temperature and pre-treatment on drying rate curves of coriander leaves
The drying rate for the coriander leaves was estimated from the difference in its moisture content in a known time interval and expressed as g of moisture evaporated per g of dry matter-min. The drying rate as a function of moisture content at different drying air temperature and with pretreatment in fluidized bed dryer is shown in Fig. 8 and Fig. 9. From the Fig. 8 and Fig. 9, it can be seen that initially the drying rate was high and subsequently it reduced with the drying time and they

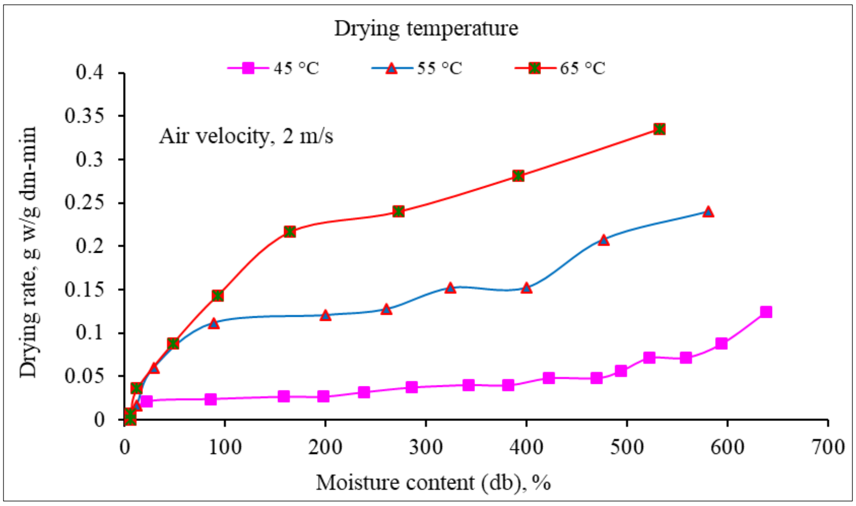

Fig 8: Drying rate curves of coriander leaves obtained at various air temperatures in fluidized bed drying

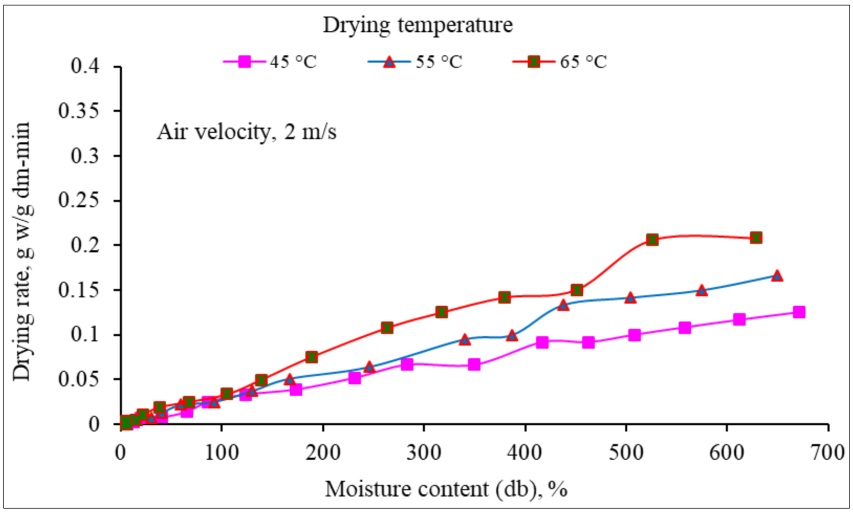

Fig 9: Drying rate curves of blanched coriander leaves obtained at various air temperatures in fluidized bed drying

followed typical drying rate curves. The maximum rate of drying for control was observed at initial stage of drying 0.125, 0.24 and 0.336 g-water/ g-DM-min and for blanched samples 0.096, 0.208 and 0.166 g-water/g-DM-min at temperature 45, 55 and 65 ºC respectively. These drying rates continuously decreased with respect to time. Difference in the drying rate of control sample and blanched sample was observed because of blanching process. Rate of drying was found to be governed by the process of diffusion as reflected by temperature dependence. With the changes in temperature, changes in the drying rate observed. From observation, constant rate-drying period was not found in drying curves. The entire drying process took place in the falling rate period; also it is evident that drying rate was higher at higher temperature with faster removal of moisture. The results were found in agreement with the earlier studies by Ankita and Prasad, (2013) [4] for spinach leaves.

Effect of temperature and pre-treatment on moisture ratio curves of coriander leaves

The initial moisture content was not same for all the drying experiments because of blanching treatment. Hence, the drying curves were normalized by converting the moisture content to moisture ratio (MR). The change in moisture profile with respect to time for different drying temperatures for both blanched and control coriander leaves is presented in terms of moisture ratio (MR) versus time graphs shown in Fig. 10 and Fig. 11.

From the Fig. 10 and Fig. 11, it can be seen that the moisture ratio of fluidized bed dried coriander leaves at 45 ºC varied from 1.0 to 0.008 and 1.0 to 0.007 at 270 and 270 min for control and blanched sample respectively, whereas at 55 ºC the moisture ratio was varied from 1.0 to 0.008 and 1.0 to 0.008 for control and blanched sample respectively at 90 and 180 min. At 65 ºC the moisture ratio was varied from 1.0 to 0.008 and 1.0 to 0.01 at 60 and 150 min for control and blanched sample. From the observation it can be seen that the moisture ratio of the samples decreased continually with drying time. As expected, increase in the temperature of drying air reduces the time required to reach any given level of moisture ratio since the heat transfer increases. This can be explained by increasing temperature difference between the drying air and the product and the resultant water migration and also there is variation of moisture ratio of blanched sample and unblanched sample. The variation might be due to blanching pre-treatment. These results were in good agreement with earlier research by Silva *et al.*, (2008) [10] for coriander leaves and stems.

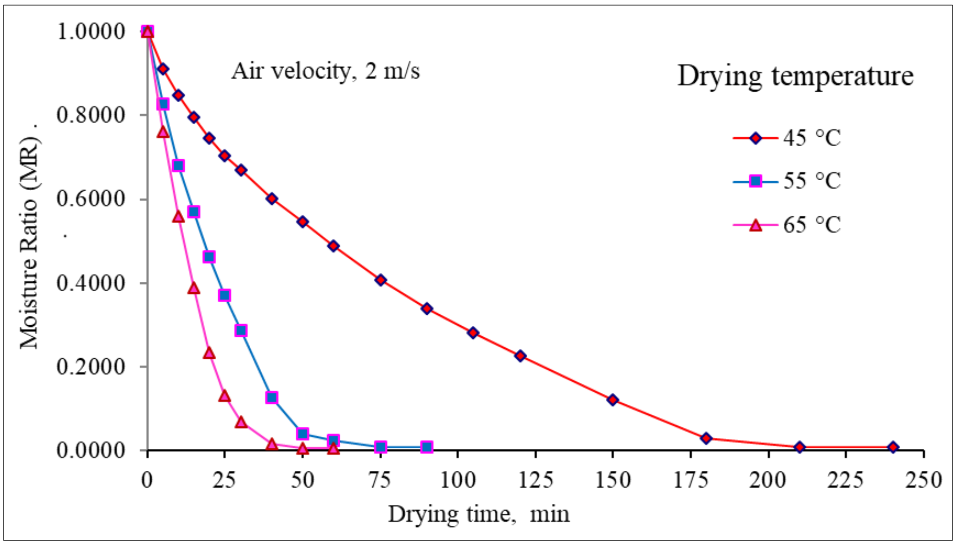

Fig 10: Moisture ratio curve of fluidized bed dried coriander leaves at various temperatures Open sun drying

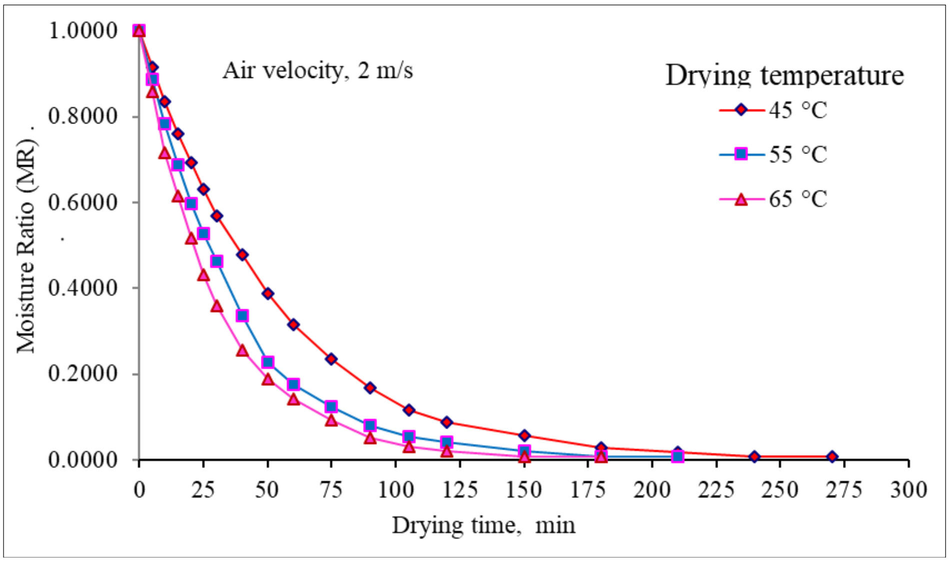

Fig 11: Moisture ratio curve of fluidized bed dried blanched coriander leaves at various temperatures

Open sun drying

Effect of temperature and pre-treatment on moisture content

The fresh Coriander leaves samples were blanched and unblanched samples were taken as control. Open sun drying required 420 min to reduce moisture content from 700% (db) to 6.4% (db) in control leaves and in case of blanched it required 450 min to reduce moisture content from 733.33% (db) to 5.42%. The control sun dried sample required less time to achieve equilibrium moisture content than blanched sun drying method. Fig.12. shows the effect of drying time on moisture content for control and blanched coriander leaves drying in sun. The curve in sun drying showed decreasing trend. The similar results were reported by Satwase *et al* (2013) [9] for drumstick leaves. The initial moisture content was not same for the blanched and control samples taken for the drying experiments due to blanching (Silva *et al.*, 2008) [10].

Effect of drying time and pre-treatment on drying rate curves of coriander leaves

Fig. 13. shows the effect of drying time on drying rate for drying coriander leaves. For control coriander leaves drying under sun the initial value of drying rate observed was 0.04 g/100g /min and decreased to 0.0019 g/100g /min after 390 min. Similarly for blanched coriander leaves drying in open sun, the initial drying rate was 0.04 g/100g /min and dropped to 0.0016 g/100g /min after 420 min. It was observed that the drying rate was seen minimum in case of sun drying.

Effect of moisture content on drying rate

Fig. 14. shows the relation between drying rate (g of moisture removed/ 100 g dry matter/min) and moisture content, % (d.b). From the figures it is evident that drying took place in falling rate period. The drying rate decreased with decrease in moisture content for all treatments.

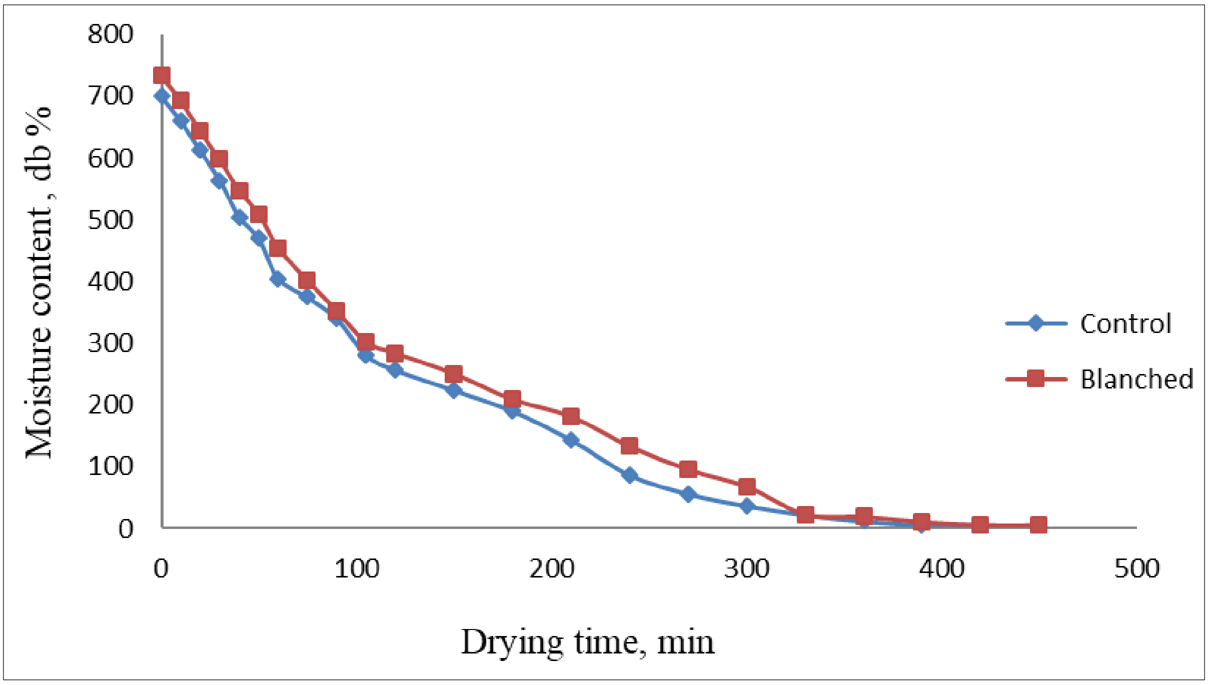

Fig 12: Effect of drying time on moisture content (Sun drying)

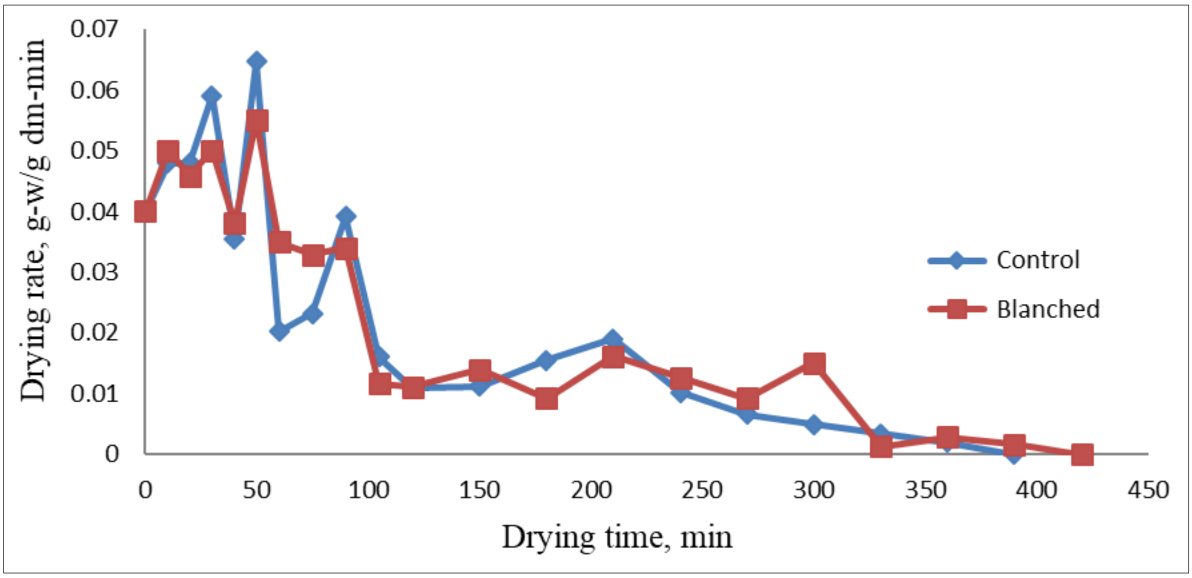

Fig 13: Effect of drying time on drying rate (Open Sun drying)

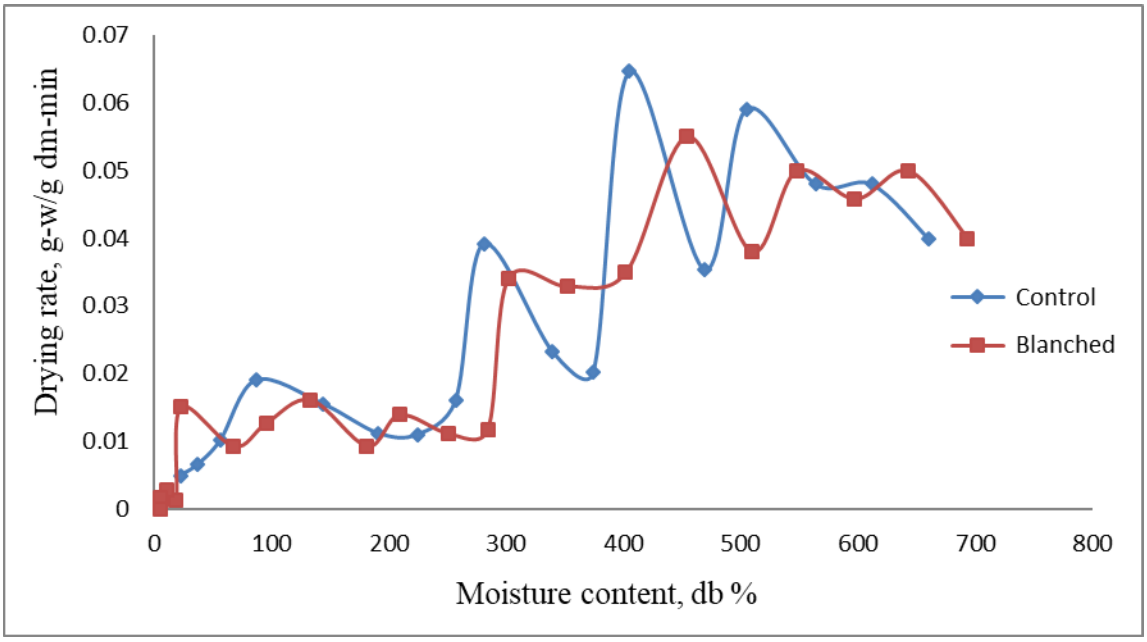

Fig 14: Effect of moisture content on drying rate (open sun drying) Shade drying

Shade drying

Effect of temperature and pre-treatment on moisture content

The fresh Coriander leaves samples were blanched and unblanched samples were taken as control. Shade drying required 720 min to reduce moisture content from 700% (db) to 5.76% (db) in control leaves and in case of blanched it required 780 min to reduce moisture content from 733.33% (db) to 5.67%. The control shade dried sample required less time to achieve equilibrium moisture content than blanched shade drying method. Fig.15. shows the effect of drying time on moisture content for control and blanched coriander leaves drying in shade. The curve in shade drying showed decreasing trend. The similar results were reported by Satwase *et al* (2013) [9] for drumstick leaves. The initial moisture content was not same for the blanched and control samples taken for the drying experiments due to blanching (Silva *et al.*, 2008) [10].

Effect of drying time and pre-treatment on drying rate curves of coriander leaves

Fig.16. shows the effect of drying time on drying rate for drying coriander leaves. For control coriander leaves drying under shade the initial value of drying rate observed was 0.04 g/100g /min and decreased to 0.0016 g/100g /min after 690 min. Similarly for blanched coriander leaves drying in shade, the initial drying rate was 0.039 g/100g /min and dropped to 0.0014 g/100g /min after 750 min. It was observed that the drying rate was seen minimum in case of shade drying.

Effect of moisture content on drying rate

Fig.17. shows the relation between drying rate (g of moisture removed/ 100 g dry matter/min) and moisture content, % (d.b). From the figures it is evident that drying took place in falling rate period. The drying rate decreased with decrease in moisture content for all treatments.

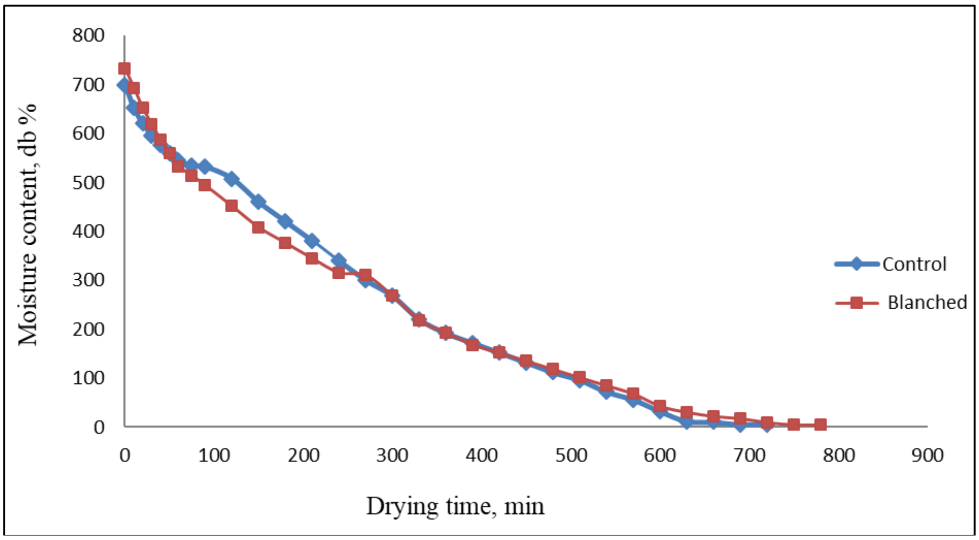

Fig 15: Effect of drying time on moisture content (Shade drying)

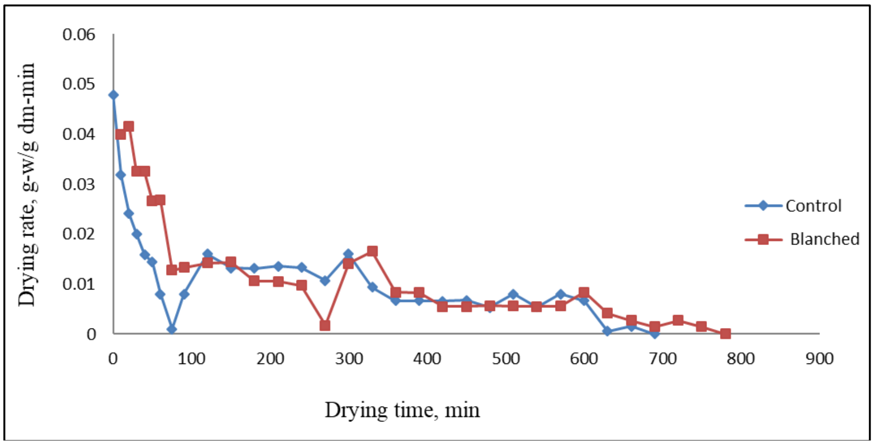

Fig 16: Effect of drying time on drying rate (Shade drying)

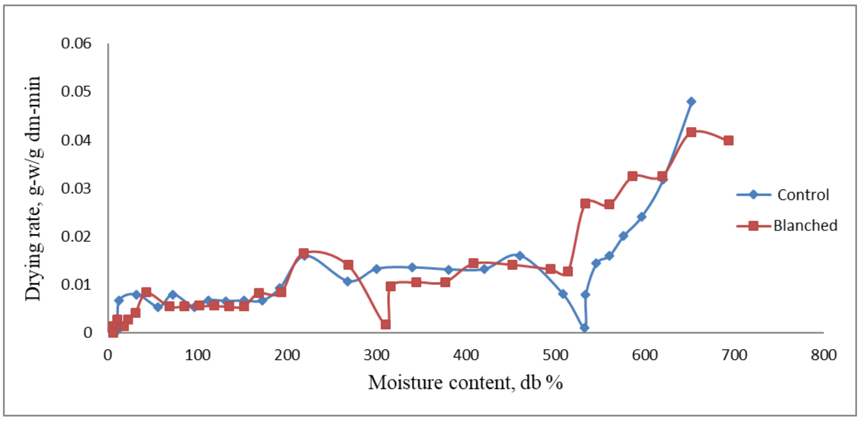

Fig 17: Effect of moisture content on drying rate (Shade drying)

Conclusions

Drying of foods is aimed at producing high density product, which when adequately packaged has longer shelf life after which the food can be rapidly and simply reconstituted without substantial loss of flavor, taste, color and aroma. The Coriander leaves were dried at an air temperatures of 45, 55 and 65 °C at a fixed air velocity of 2m/s for tray dryer and fluidized bed dryer. There was a wide variation in drying time from 180 to 390 min and 60 to 270 min for the range of drying air temperatures (45 to 65 °C) taken for tray dryer and fluidized bed dryer respectively. Minimum drying time was observed for high air temperature (65 °C) for control sample for tray dryer and fluidized bed dryer. The results showed that fluidized bed drying of the coriander leaves was faster than for convective tray drying. The coriander leaves took 180 to 390 min to dry under tray drying to bring down initial moisture content (700.00 to 733.33 per cent) to final moisture content in the range of 5.20 to 5.91 per cent (db) at different studied temperatures. Whereas fluidized bed dryer took only 60 to 270 min to dry coriander leaves from to almost same levels of initial and final moisture contents. Also, Drying of coriander leaves took place in falling rate period and constant rate period was completely absent in both tray drying and fluidized bed drying experiments.

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