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Drying kinetics of ajwain (*Trachyspermum ammi* L.) leaves

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Abstract
Ajwain (*Trachyspermum ammi* L.) leaves are good source of phytochemicals such as saponins, terpenoids, tannins, alkaloids, phenol, philobatannins and flavonoids. The dark green leaves of ajwain contain many valuable nutrients, especially the antioxidant carotenoids, lutein and zeaxanthin. Fluidized bed drying of ajwain leaves was conducted at 45, 50, 55 and 60 ^{O}C air temperature levels and 2 ms^{-1} air velocity to evaluate the drying kinetics. The time taken for dying at 60 ^{O}C air temperature was found minimum (120 min) as compared to 45 ^{O}C (210 min), 50 ^{O}C (180 min) and 55 ^{O}C (150 min) air temperatures. The effective moisture diffusivity values were increased with increase in air temperatures and varied from 9.85×10^{-11} to 2.42×10^{-10} m^2s^{-1}. The water activity of ajwain leaves were found to be decreased with increase in air temperatures. The quality of the product dried at 60^{O}C air temperature was found to be a superior in terms of colour value.

Keywords: Phytochemicals, Antioxidant carotenoids, lutein, zeaxanthin, Moisture diffusivity

Introduction

Ajwain (*Trachyspermum ammi* L.) is an annual aromatic herb which belongs to the family Apiaceae. Ajwain has several other common English names, such as carom, Ethiopian cumin, wild parsley, and bishop's weed. The plant is native to Egypt and widely cultivated all over Iraq, Iran, Afghanistan, Pakistan, and India. In India, ajwain is grown on a large scale in the states of Rajasthan, Gujarat, and Andhra Pradesh and grows on a small scale in Uttar Pradesh, Punjab, Bihar, Madhya Pradesh, Tamil Nadu, West Bengal and Karnataka [1]. Rajasthan alone produces about 90 per cent of India's total production. Ajwain grows well on all types of soil but does well on loam soil with pH 6.5-8.2 at temperature of 15-25^{O}C and relative humidity between 65-70 percent. Harvesting is done during later parts of winter or earlier in spring [2]. It is an erect annual plant with a striate stem. It has feathery leaves 2-3 pinnately divided, segments linear with flowers terminal and compound. The most utilized part of the herb is the small caraway-like fruit, which is especially popular in Indian savoury recipes. The herb has a very pungent smell and, emits a strong aroma when rubbed, similar to the smell of thyme [3].

Ajwain has been well known as an Ayurvedic spice since ancient times. Ajwain possesses some pharmaceutical effects such as antiviral, anti-inflammatory [4], antifungal [5], antipyretic [6], anti-filarial [7], analgesic [8, 9], anti-nociceptive [10] and antioxidant activity [11]. Phytochemicals are the major contributor towards its odour, taste and medicinal values. The phytochemical components of ajwain include flavonoids, saponins, tannins, and glycosides [12]. The above-mentioned literature has proved the pharmaceutical potential of ajwain herb.

Drying is the simple and economical method for preservation of food material. It has advantages like reducing volume and bulk, easy to transport, and adds value in terms of nutritional benefits and economical advantage [13]. Various drying techniques have been developed over years for food materials and the selection of technique depends upon the physical properties and drying behaviour of raw materials as well as the required quality of the end product. Mechanical dryers provide a uniform and hygienic dried product. The mechanical dryer takes less time to dry the product and also reduces losses [14]. Convective air-drying technologies include hot air tray drying, fluidized bed drying, heat pump drying, microwave drying and sprouted bed drying. When the drying takes place at high temperature with long drying time, there is an undesirable thermal degradation of the final products. In this case, energy requirement is high and drying efficiency is low [15]. Fluidized bed drying is an example of suspended bed dryers because the food particles are supported and carried by the hot air. Fluidized bed drying has many advantages comparing to other drying techniques [16].

Researchers have been reported on several studies of the fluidized bed drying properties of leafy vegetables such as celery leaves [17], cabbage [18], green peas [19], green chilli [20], spinach and Swiss chard and leek [21]. Very scanty literature is available on drying of ajwain leaves. On this account a study of fluidized bed drying of ajwain leaves was carried out with specific objective to analyse the drying kinetics.

Materials and Methods

Fresh ajwain plants were procured from Dhariyawad, Pratapgarh district, Rajasthan. Good quality leaves were selected and washed to remove dust and dirt for further processing. The moisture content of the fresh ajwain leaves was determined as described by AOAC, [22].

Fluidized bed drying

A fluidized bed dryer (manufactured by Sherwood Scientific Ltd. Cambridge, England) was used for drying of ajwain leaves. The air temperature and velocity can be regulated in this dryer. The dryer was simple, compact, portable and easy to work. The cabinet contained the air distribution system and air was drawn into the chamber through a mesh filter provided at the bottom of the cabinet and blown by the centrifugal fan over a 2-kw electrical heater. The tube unit consisted of a container with a fine mesh distributor and stainless-steel support. A filter bag, which fitted over the top of the tube, retained any particles expelled from the fluidized bed. The fluidized bed dryer had PID controller with a range of 0-200^{O}C; which regulated the operation of the heater to maintain the desired present temperature of the drying air.
The fluidized bed dryer was run idle with no load for about 30 minutes to achieve constant drying conditions. The ajwain leaves (100 g) were dried in fluidized bed dryer at 45, 50, 55 and 60^{O}C air temperature and 2 m/s air velocity. The weight of sample was recorded for an interval of 5 minutes using a top-pan electronic balance (Adair Dutt, ± 0.001 g) until the weight of the sample reached a constant value and average of three replications were used for calculation. The moisture content of the samples at the end of each interval was calculated by using mass balance equation. Drying experiments were repeated in a similar manner at different air temperatures. The moisture loss data during drying were analysed and moisture ratio at various time intervals were calculated. The drying rate of the sample was calculated by using following equation [23]

$$\text{Drying rate (R)} = \frac{WML\ (g)}{Time\ interval\ (\text{min}) \times DM(g)} \ \ldots (1)$$

Where,
R = Drying rate, g water/ g dry matter-min
WML= Weigh of moisture loss during the time interval
DM = Dry matter, g

Moisture diffusivity

Effective moisture diffusivity (D_{eff}) of the fluidized bed dried ajwain leaves was calculated by using following equation as suggested by Crank [24].
When the food products with uniform moisture content is assumed as one-dimensional moisture flow, the solution of Fick's equation for infinite slab shape is

$$MR = \left[\frac{M - M_e}{M_O - M_e}\right] = \sum_{n=1}^{\infty} \frac{4}{\beta_n^2} exp\left[-\frac{\beta_n^2 D_{eff}}{r_c^2}\right] = \frac{8}{\pi^2} exp\left[-\frac{\pi^2 D_{eff} t}{L^2}\right]$$

Where
MR = Moisture ratio, dimensionless
M = Moisture content at specified time interval, g of water/ g of dry matter
M_O = Initial moisture content, g of water/ g of dry matter,
M_e = Equilibrium moisture content, g of water/ g of dry matter
β = Roots of Bessel moisture content
L = Slab thickness, mm
t = Time, hour
A general form of above equation could be written as follows [25].

$$D_{eff} = \frac{Slope \times 4H^2}{\pi^2}$$

Where, D_{eff} is the effective moisture diffusivity of the ajwain leaves, H is the characteristics dimension *i.e.*, half the thickness of the leaves (0.0001m).

Quality Evaluation: The quality of dried ajwain leaves was evaluated on the basis of rehydration ratio, water activity and colour (L*, a* and b*) values. Rehydration ratio is the ratio of mass of the rehydrated sample to mass of the original material. Water activity of sample was measured by using a digital water activity meter (Model- novasina). Colour value was measured using Hunter Lab colorimeter.

Results and Discussion

Effects of air temperature on drying time

The moisture content of ajwain leaves decreased exponentially with the drying time under all drying air temperatures. The time required for drying the sample up to a moisture content of about 7.80 to 10.55 per cent (db) at 45, 50, 55 and 60^{O}C air temperatures was observed to be 210, 180, 150 and 120 min respectively. The percentage reduction in time were about 14.28 percent, 28.57 per cent and 42.85 per cent as temperature increased from 45 to 50^{O}C, 45 to 55^{O}C and 45 to 60^{O}C, respectively. The time required for drying was observed to decrease with increase in air temperature as mentioned in Table 1. There was significant reduction in drying time with increase in air temperatures. The findings are in lined with the reports for fluidized bed drying of fenugreek leaves [26] and spinach, Swiss chard and leek [21].

Table 1: Drying time for ajwain leaves for fluidized bed drying at different air temperatures

Temperature (^{O}C)	IMC (%db)	FMC (%db)	Time (min)	Reduction in time (%)
45	248.43	8.22	210	-
50	248.43	10.55	180	14.28
55	248.43	8.32	150	28.57
60	248.43	7.80	120	42.85

The reduction in drying time with increase in air temperature is quite evident. The rate of drying was higher for high drying temperature. Hence it can be stated that the drying air temperature has pronounced effect on the removal of moisture content. These observations are in line with the findings for drying of mint leaves by Doymaz [27], Sharma [28] and Kadam [29] for drying kinetics of onion. It can be seen from figure no.1 that no constant rate period was found during fluidized bed drying of ajwain leaves. The entire drying has taken place in falling rate period under all drying temperatures.

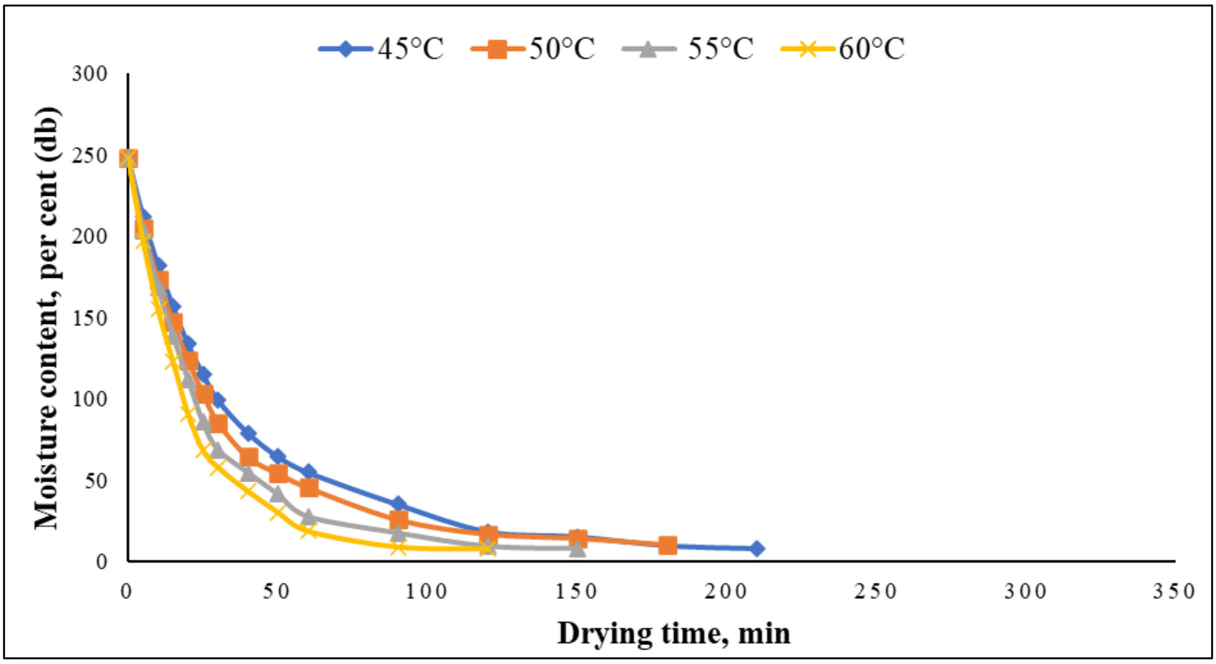

Fig 1: Variation in moisture content with drying time for fluidized bed drying

Drying rate of ajwain leaves were analysed and regression equations of polynomial form were derived. The values of regression coefficient (R) of polynomial equations were given in Table 2. The data implies that good correlation exists between the drying data as the coefficient of determination is more than 0.99. similar trend was also reported for mushroom by Murumkar [30].

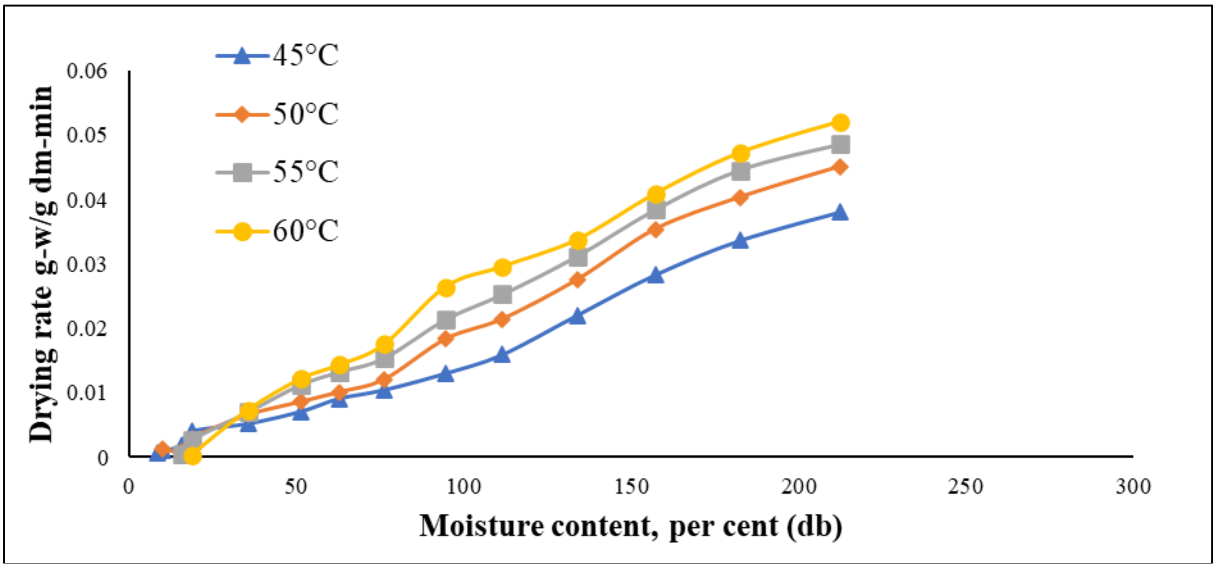

Fig 2: Variation in drying rate with moisture content for fluidized bed drying

Table 2: Drying rate equation with respect to moisture content (db)

Drying air temperature (^{O}C)	R^2
45	0.9923
50	0.9942
55	0.9928
60	0.9930

Effect of air temperature on moisture diffusivity

The moisture loss data were analysed and moisture ratio at various time intervals were determined. The ln (MR) was plotted against with drying time in order to find out the moisture diffusivity for ajwain leaves for all temperatures. The curve for variation in ln (MR) with drying time for all temperatures was found to be linear with inverse slope. The slope of straight lines became steeper and effective moisture diffusivity values were found to increase with increase in air temperature. The effective moisture diffusivity varied from 9.85×10^{-11} to 2.42×10^{-10} m^2/s during drying of ajwain leaves for air temperature of 45 to 60 ^{O}C.

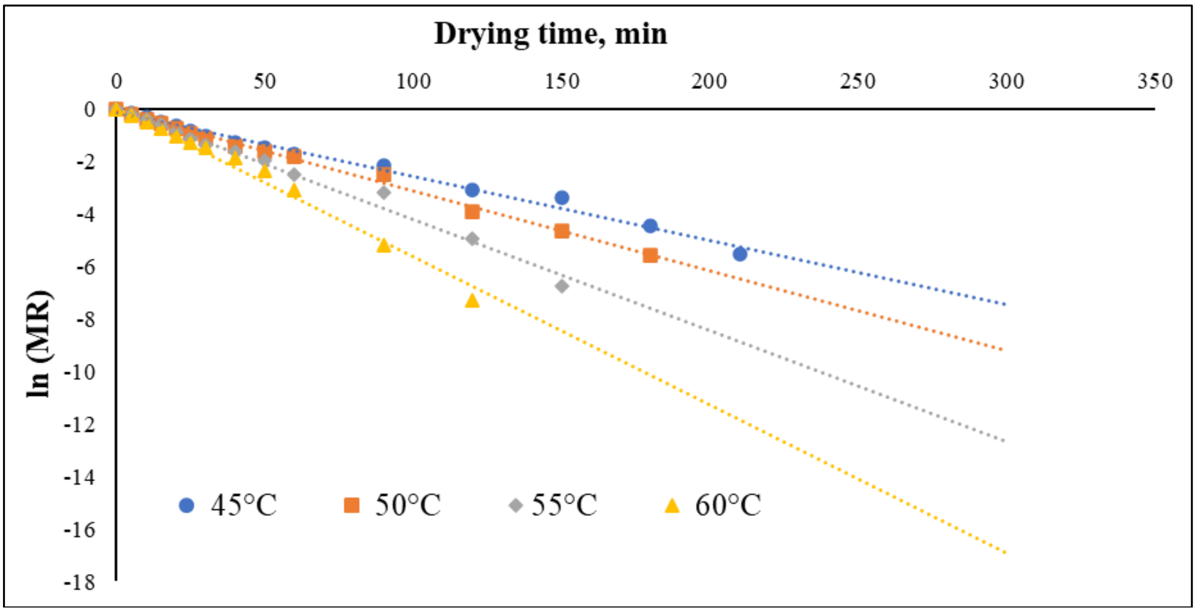

Fig 3: Variation in ln (MR) with drying time at different air temperature

The present findings are in conformity with dried vegetables [31]. The values of moisture diffusivity for fluidized bed drying of ajwain leaves at different air temperatures along with coefficient of correlation (R^2) are given in Table 3. The ln (MR) and drying data were observed best fit representing straights line equations with coefficient of determination $R^2 > 0.98$ for all air temperatures indicating good correlation between the drying parameters.

Table 3: Effective moisture diffusivity of ajwain leaves during drying

Drying air temperature (^{O}C)	Moisture diffusivity (m^2/s)	R^2
45	9.85×10^{-11}	0.9895
50	1.23×10^{-10}	0.9955
55	1.71×10^{-10}	0.9883
60	2.42×10^{-10}	0.9891

Quality analysis

The rehydration ratio for fluidized bed dried ajwain leaves at 45, 50, 55 and 60^{O}C air temperature was found 3.21, 3.15, 3.21 and 3.23 respectively. Water activity of samples was observed to decrease with increase in air temperatures from 45 to 60^{O}C. The values for water activity were found 0.191, 0.186, 0.183 and 0.144 at air temperatures of 45, 50, 55 and 60^{O}C, respectively. The lowest water activity at highest air temperature may be due to higher evaporation rate influencing the moisture content and consequently water activity of the products [32].

The colour (L*, a* and b*) values of fresh ajwain leaves was found to be 24.71, -2.05 and 8.24 respectively. Colour (L*, a* and b*) values of fluidized bed dried ajwain at 45, 50, 55 and 60^{O}C air temperatures were found to 47.7, 4.45 & 27.52; 48.47, 3.45 & 25.48; 51.80, 1.53 & 26.50 and 57.30, 1.20 & 23.53, respectively. The observed data for L*, a* and b* values under different drying temperatures has been given in Table 4. The L-values of fried ajwain was found to be increase with air temperatures. The a value was found to decrease when air temperature increased from 45 to 60^{O}C. similar trends were found for fluidized bed drying of curry leaves by Dawn and Naik [33].

Table 4: Effect of air temperature on different quality parameters

Drying air temperature (^{O}C)	Colour value			Water activity	Rehydration ratio
	L*	a*	b*		
45	47.79 ± 0.829	4.45 ± 0.398	27.52 ± 1.359	0.191 ± 0.004	3.21 ± 0.125
50	48.47 ± 1.062	3.46 ± 0.287	25.48 ± 0.864	0.186 ± 0.005	3.15 ± 0.120
55	51.80 ± 0.953	1.53 ± 0.186	26.50 ± 0.442	0.183 ± 0.036	3.21 ± 0.198
60	57.30 ± 0.893	1.20 ± 0.063	23.53 ± 0.368	0.144 ± 0.029	3.23 ± 0.130

Conclusion

Drying time, drying rate and moisture diffusivity were found to be dependent on air temperatures used for drying. The minimum drying time of 120 minutes was observed at 60 ^{O}C air temperature and maximum time of 210 minutes at 45 ^{O}C air temperature. The effective moisture diffusivity increased with increase in air temperature. The values varied from 9.85×10^{-11} to 2.42×10^{-10} m^2/s for air temperatures from 45 to 60 ^{O}C. The water activity of ajwain leaves was found to be decrease with increase in air temperatures. The quality parameter like rehydration ratio and colour values were evaluated for the all products. The rehydration ratio is minimum for the ajwain leaves dried in fluidized bed dryer at 50^{O}C. The product dried at 60^{O}C air temperature was found to be superior in terms of colour (L*, a* and b*) values 57.30, 1.20 and 23.53 respectively.

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