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Design and development of Phase Change Material (PCM) based hybrid solar dryer for herbs and spices

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ABSTRACT

Herbs (green leafy plant mass) are highly perishable in nature containing more than 80% moisture. Moisture needs to be removed to less than 11% for storing it for longer period of time. A phase change material (PCM) based solar dryer was developed consisting of collector of area 0.64m^2 and three trays of 0.42 m^2 of area each in the drying chamber. The dryer consists of a real time data acquisition system for recording the temperature, humidity and moisture loss. Collector was also filled with 20 kg paraffin wax as a latent heat storage material for continuous drying after sunshine. Performance of the developed dryer was evaluated by drying fresh mint and coriander leaves having initial moisture content of 82–86 % (wb) and compared with developed dryer without PCM and shade drying considering both the drying parameters and quality parameters of the dried herbs. The developed dryer with PCM was found to produce significant difference in drying rate ($P<0.0001$) for both herbs compared to dryer without PCM and shade drying. All the quality parameters in terms of retention of the total phenolic content and flavonoid, magnesium and iron content found to have significance difference ($P<0.0001$) compared to without PCM and shade drying. The developed solar dryer provides a promising alternative for continual drying of other materials also including herbs even after sunshine hours with real time data acquisition system and also found to be superior in retaining quality.

Key words: Herbs, Phase change material, Solar dryer, Spices

Drying of herbs and spices is one of the most important post-harvest activities. It is primarily intended to decrease the moisture content. For some spices such as chili and pepper, drying is not only for preservation purposes but also for modifying the tastes and flavors in order to increase their market values. Natural sun drying is widely used in developing nations to dry herbs and spices. In addition to non-uniform drying products are also contaminated by insects and birds. In the dried products, toxic substances such as aphlatoxin generated by molds are often discovered owing to rewetting of the products during drying owing to rain and too slow drying rate during the rainy season. This is one of the primary issues that hinders the development of exports to global markets of herbs and spices.

Solar drying is an important technique for food security and solar collector's is abundantly used technology for the dehydration of fruits and vegetables in good quality and aroma, safe from insects attack (Henderson 1976).

Number of drying methods include air drying, sun drying, solar drying, hot air oven drying, microwave drying, freezing drying, drying of infrared drying and vacuum drying. Most of these drying methods require advanced machinery and tools, undisturbed power supply, qualified workforce and continuous installation houses, except for sun and solar drying. These mechanical drying systems, however, suffer from the constraints of high original and maintenance costs, sufficient accessibility of size and absence of expertise to run these dryers. Due to these limitations, these dryers are rarely used by smallholders in the developing countries. (Alavi *et al.* 2012). A hybrid solar dryer was designed and developed for drying of flowers with stone pebbles as heat storage (Pachpinde 2019).

Continuous drying mechanism is required for proper drying of the herbs and spices to maintain its quality and automation system is required for solar dryers to get the better results. The demand for low cost on farm solar dryers that could efficiently utilize the available green energy can be produced locally and retains the quality of the product after drying and considering these specifics the present research work for developing solar powered phase change material (PCM) based dryer was undertaken.

MATERIALS AND METHODS

Herbs and spices selected for the research work were mint and coriander. The selection was based upon the most widely used herbs and spices and its availability. Mint is

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an aromatic herb belonging to the family Lamiaceae and its common name is *Mentha spicata* L. These herbs are annual or perennial and are widely cultivated around the world to acquire their unique herbal features. Mint leaves are known for its special features like refreshing, antiseptic, antiasthmatic, stimulative, diaphoretic, stomachic and antispasmodic. Mint leaves are used in different cuisines in both fresh and dried forms. Essential mint oil is also used and is extracted for many industrial applications through distillation method, either from new mint leaves or from semi-dried or dried leaves.

Coriander (*Coriandrum sativum* L.) belongs to the family Apiaceae. Coriander leaves are mostly used for medicinal and culinary purposes. It assists in increasing the nutritive value of food, and also provides good source of minerals, proteins, and fat. Coriander can be consumed as the fresh leaves and dried seeds, these are commonly used in cooking. India being the largest producer, consumer, and exporter of coriander in the world producing averages around 3 lakh tonnes annually.

The leaves were separated from the stem and weighed by using an electronic weighing balance. The bulk density was calculated with the help of a box of dimensions 10cm × 10cm × 10cm. It was filled with the fresh leaves and weighed while care should be taken that compaction does not occur. The experiment was repeated 3 times and readings were recorded. Mathematically,

$$\text{Bulk Density} = \frac{\text{Weight of material (kg)}}{\text{Volume of bulk material (m}^3)}$$

Design values for collector area of solar dryer were determined based on selection of tilt angle and collector surface area for solar insolation. Optimal angle is required for installing a solar collector for maximum absorbance of solar energy. The optimal tilt angle is the angle where the solar radiation will arrive perpendicularly upon the surface. Angle of tilt (β) of the solar collector is determined according to Alamu (2010).

$\beta = 10^0 + \text{lat } \phi$, where, ϕ is the latitude of the collector location. New Delhi lies along the latitude 28.70°N. Hence the optimum value of angle of tilt (β) used for the collector is:

$$\beta = 10^0 + 28.7^0 = 38.7^0$$

The insolation value for New Delhi, i.e. average global horizontal irradiance on the horizontal surface is 5200 Wh/m^2 and the average annual bright sunshine hours are 7.35. The value of insolation for Delhi was calculated as,

$$H = 5.2 \text{ x } 7.35 = 706.89 \text{ W/m}^2$$

So the average effective ratio of solar energy on tilted surface to that on the horizontal surface R is given by: R = 1.0035 × H

Therefore the value of effective ratio of solar energy (R) becomes: R = 1.0035 × 706.89 = 709.36 W/m^2

For determining the mass flow rate of air, the average air velocity was considered as Va = 0.18 m/s. The air gap height was taken as 5 holes each of 1 cm, i.e (1 × 5) cm = 5cm = 0.05m and the width of the collector was assumed to be 0.8 m.

Volumetric air flow rate is given by: Va′ – Va × air gap × width of collector

Therefore, Va′ – 0.18 × 0.05 × 0.8 – 0.0072 m^3/s

Mass flow rate of air is given by, ma = V′ × ρ_a

Where, ρ_a is Density of air = 1.28 kg/m^3

Therefore, ma = 0.0072 × 1.28 = 0.009216 kg/s

The area of collector was determined by the following equation,

$$Ac = \frac{m_a \times Cp \times \Delta T}{\eta \ \times R}$$

where, Ac = Area of collector, m^2, m_a= Air flow rate, kg/s, Cp = Specific heat of air, J/kg K, ΔT = difference between ambient temperature and drying temperature, °C, η = Thermal efficiency in fraction, R = average effective solar insolation on tilted surface, W/m^2.

$$Ac = \frac{0.009215 \times 1020 \times 30}{0.5 \times 709.36} \times 100$$

Hence, the length of the collector was calculated as,

$$L = \frac{Ac}{\text{width of collector}} = \frac{0.795}{0.8} = 0.993 \text{ m}$$

So a dryer with collector dimensions 0.993m × 0.8m was fabricated having collector area equal to 0.795m^2. This was the optimum area for receiving the solar insolation and heating the air.

Drying cabinet mainly consists of four important parts (basic frame, drying chamber, trays and doors for loading and unloading of products. It accommodates trays of different sizes which facilitate uniform and expeditious rate drying. Dryer size and the requirement of energy for drying were decided in accordance with the moisture to be removed from the leaves to bring it down to safe moisture level. Polyurethane (PUF) Insulation was provided in the drying chamber to prevent heat loss to the surrounding as follows. The size of the drying chamber was decided as 80 cm length and 65 cm width.

Designed capacity of the dryer was 3 kg and bed thickness was taken as 4 cm for the herbs. Number of trays used was based on the capacity and allowable thickness of the leaves to be dried in thin layer drying. Perforated trays were used for easy flowing of air through the leaves to achieve sufficiently higher drying rate. Sizes of perforations of the trays were decided on the basis of size and shape of the herbs. Area of the tray was kept (0.7m × 0.6m) to fit easily inside the chamber. Height of the tray was kept as 4cm and the gap between the trays were kept as 10 cm. Number of trays was calculated using the following formula:

Number of tray = Mp/(Area of one tray × thickness of seed layer × ρ), where, Mp= mass of the product, ρ= density of the leaves. Based on this number of trays were taken as 3.

Amount of moisture to be removed from the product,

m_w (kg) was calculated using the following equation (Tonui *et al.* 2014). The initial moisture content was calculated by using hot air oven method.

$$m_w = m_p \times \frac{mi - mf}{100 - mf}$$

where, mi= initial moisture content of the herbs (%), mf= final moisture content of the herbs (%), mw = mass of water to be removed (kg) and mp = initial mass of the product (kg). So m_w=2.53 kg.

Thus, the moisture to be removed for 3 kg of leaves for bringing down to the safe level moisture of below 11% was found to be 2.53 kg. Amount of heat required (Q) to remove the moisture from the herbs was determined by the following equation (Singh and Sahay 2004).

$Q= m_p C_p \Delta Tp + m_w h_{fg}$, where, mp = mass of product, Cp= Specific heat of product (Singh and Sahay 2004).

$$C_p = \frac{m_w}{100} \times C_w + \frac{100 - m_w}{100} C_d$$

where, C_w= specific heat of water (4.18 kJ/kgK), C_d= specific heat of dry matter (1.514-5.174 kJ/kgK) and ΔTp= change in temperature before and after heating (°C),

Therefore, Cp=5.14 kJ/kgK,

The latent heat of evaporation (hfg) is the function of temperature and moisture content of crop. The latent heat of vaporization can be calculated by following equation (Ogheneruona and Yusuf 2011),

hfg = 4.186 (597 – 0.56 (Tpr+273) = 1791 kJ, where, Tpr (°C) is the product temperature. Therefore, Q= 4546.14 kJ

Paraffin wax was used as a phase change material (PCM) for storing large amount of latent heat energy (Fig 1). During sunshine hour the energy is absorbed by the collector which heats the air inside it and that useful energy cause melting of the PCM material. Many factors needs to be considered while selecting a phase changing material. PCM which are having high thermal conductivity, high heat of fusion, high density, high specific heat, reliability with long term cycle and dependable freezing behavior are considered as an ideal PCM (Table 1). 20 kg Paraffin wax used and was kept in the tray made of galvanized iron (GI) having dimension of 63×53×15.5 cm^3.

All the functional units of the dryer were fabricated and assembled together to develop the dryer. Optimum design values were calculated like collector area was found out to be 0.795 m^2 for receiving the solar radiation, drying chamber of dimension (0.8×0.65) m^2 containing 3 trays of area (0.7m × 0.6m) (Fig 1). Quantity of heat required for drying was found out to be 4546.14 kJ/kg. Automation system was developed for continuous measurement of temperature, humidity and weight loss at a definite interval of time.

Two 12V(5W) DC fans were used for pulling the heated air from the solar collector into the drying chamber and facilitate the movement of moist air out of the drying chamber through chimney. A solar photovoltaic panel of 100 Watt/12 Volt was used for recharging the battery throughout the day so that it can be used for operation of fan and other system during night.

Automation system was developed for measuring and recording the temperature and relative humidity of the ambient air, collector, drying chamber and chimney and also to record the weight loss in the product at a constant interval of time. Automation of the real time data acquisition system was programmed through Arduino Mega 2560 microcontroller board with ATmega 2560 microcontroller chip. Automation system was developed using Arduino Mega 2560, DHT22 sensor, SD card module, RTC and LCD display with I2C, load cell and HX711 amplifier.

An innovative continuous weight measuring system was developed for this dryer. This system consists of an I section having 4 holes on the 4 corners of the section. Four thin metal wires (1 mm) were taken and put on those holes so that it can sustain the weight of the trays. Trays are in hanging position supported by the wires and the I section. The load cell was placed at the center of the I section to

Table 1 Properties of paraffin wax

Properties	Values
Specific heat	2.14 – 2.19J/kgK
Heat of fusion	200-220 J/g
Latent heat	255 KJ/kg
Thermal conductivity (solid)	1.12 W/mK
Thermal conductivity (liquid)	0.24 W/mK
Density (solid)	850 kg/m^3
Density (liquid)	800 kg/m^3
Melting point	52^0C

Fig 1 Experimental set up of the dryer.

make the system properly balanced. Load cell was covered with the insulating material to avoid the error in measurement due to the effect of temperature. Materials to be dried were put on the trays. The loss of weight indicated the drying characteristics of the material on the trays. Depletion in weight was recorded at different interval of time and hence drying rate was computed.

A load cell (20 kg capacity) was used to measure the force which gives the output in electrical signal and the magnitude of the electrical signal is proportional to the force applied. Power was supplied to the load cell by using solar panel of 12V/100W. HX711 amplifier was used in load cell. As the output from any transducing element is too small to read and record any data so HX711 was used as an signal conditioning element for load cell to obtain the output in desired form.

RESULTS AND DISCUSSION

To obtain the optimum operating condition of the PCM based solar dryer, developed dryer was evaluated at three inlet velocity and two levels of bed depth for the selected herbs. For optimizing the dryer different conditions like overall drying rate and total drying time was calculated. The optimized condition was set in the dryer and the comparative study was done for drying of fresh herbs in developed dryer with PCM, dryer without PCM and shade drying on the basis of parameters like Overall drying rate, total drying time, phenol content, flavonoid content, magnesium content and iron content. For optimizing the conditions in the dryer, process of drying was started at 9:30 AM and weight loss was recorded by the load cell. For comparative study, drying process was start at 11:30 AM. All the experiment was replicated three times.

Fresh mint leaves and coriander leaves were purchased before doing each experiment from the local market Ghazipur, New Delhi, India. The branches were thoroughly washed in clean water to remove all the dirt adhering to the leaves. Only green and healthy leaves were used for experimentation and the extra moisture was removed out by tissue paper. Fresh mint and coriander leaves were loaded uniformly over stainless steel trays (Fig 2).

Total phenolic content of mint leaves was determined by Foli-Ciocalten method (Singleton *et al.* 1999). Mint sample of 5g was taken and grind using pestle and mortar with 10ml of 80% ethanol. The homogenate is centrifuged at 10000 rpm, for 20min at 4°C. Supernatant taken out for further analysis. From this supernatant 100µl of aliquot is taken into a test tube and 3ml of distilled water and 0.5ml of (1N) Foli-Ciocalten reagent added to it. After 3 min, 2 ml of 20% Na_2CO_3 is added to each tube and mixed thoroughly. Then, Absorbate is measured at 750 nm by using UV spectrophotometer (double bean UV -VIS Spectrophotometer, UV 5704SS, ECIL, India). The calibration curve was made by preparing acid concentration were expressed in terms of micromole/g.

$$\text{Total Pheneolic Content (mg/100g)} = \frac{(A \times \text{Volume made up (ml)}) \times \text{Dilution} \times 100}{(\text{Aliquot taken (ml)} \times \text{Weight of sample (g)} \times 1000}$$

$$\text{where, } A = \frac{\text{Abs. 750} - \text{Intercept}}{\text{Slope}}$$

Aluminium trichloride method (Dewanto *et al.* 2002) was used to determine the Total flavonoids content (TFC) in fresh and dried mint samples with slight modifications. A 10-g sample is crushed in pestle and mortar with 80% ethanol. A 1 ml sample extract is taken in test tube and 4.3ml of distilled water is added to it. Immediate after this 0.3ml of 5% sodium nitrite is added. After 5 min, 0.3ml of 10% of aluminium chloride ($AlCl_3$) was added and after 6min, 2ml of 1M NaOH is added to the mixture in a test tube. Further 2.1 ml of distilled water is added to make final volume of 10ml. the mixture was vortexed and absorbance was measured at 210nm by using spectrophotometer against the blank (water) and flavonoid content is expressed as mg quercetin equivalent/100g. for standard curve quercetin is used in concentrations (10-60 µg).

$$\text{Total Flavnoids Content (mg/100g)} = \frac{(A \times \text{Volume made up (ml)}) \times \text{Dilution} \times 100}{(\text{Aliquot taken (ml)} \times \text{Weight of sample (g)} \times 1000}$$

$$\text{where, } A = \frac{\text{Abs. 750} - \text{Intercept}}{\text{Slope}}$$

Atomic Absorption Spectrophotometer was used to determine the Iron and magnesium content (mg/100g) of fresh as well as dried coriander leaves. The 0.5 g of sample was digested with 10 ml of di-acid ($HClO_4$: H_2SO_4 4:1) in conical flask and heated till one drop remain in conical flask. Further, it was filtered with Whatman filter paper no.

Fig 2 Loading of the leaves on the tray.

1. Finally, the volume was made up to 100 ml with distilled water. Iron content was determined using the formula (Cheng 1951) Fe (ppm) = (Reading – Black) × 200.

Drying of herbs under shade and drying of herbs without PCM were taken as control sample. Shade dried and without PCM dried sample was compared with the treatment found optimum in terms of drying characteristics of the leaves and also the performance parameters of the dryer. For shade drying the leaves were kept out in open condition. The weight was recorded every 1 hr interval. The drying was stopped once the safe level moisture content was achieved.

Fig 3 shows the variation of moisture with time for all the treatment combinations in coriander herb, it was found that for moisture reduction of 84-88% to 9-11% the drying time varied between 7.46 h to 15.15 h for various treatment combinations. The treatment combination T4 (3cm, 6 m/s) was found to have least drying time and hence fastest rate of drying. In drying of mint from moisture content of 84-88 % to 9-11% the drying time was found to vary from 6.85 h-14.08h. Treatment combination T4 (3cm, 6m/s) was found to have the least drying time and hence account for highest drying rate (Fig 4).

The least mean square values for rate of drying calculated in various treatment combination varied from 5.3 to 10.61% moisture per hour. Treatment combination T4 (2 kg and 6 m/s) was having highest least square mean value of drying rate among various treatment combinations.

It was found that increasing the bed depth of herb from 3cm to 4cm had a significant effect on drying rate of coriander. The least square mean was found to vary between 5.82– 8.75 percentage moisture removed per hour. Increasing the bed depth of the herb from 3cm to 4cm was found to produce a significant effect on the drying rate of mint herb. The least square mean value of increase in overall drying rate of mint was found to vary from 6.69- 10.61% moisture per hour. Thus the treatment combinations with lower bed depth (3cm) have better drying compared to higher one.

It was found that the drying rate in coriander significantly increased from 5.9 to 7.82 % of moisture removed per hour on increasing the inlet air velocity from 2 to 4 m/s. However the increase in the drying rate 7.82 to 8.13 percentage of moisture removed per hour produced as a result of increasing the inlet air velocity from 4 to 6 m/s was non-significant.

Least square mean of treatment combinations varied from 5.9-8.13% moisture per hour. However the increase in the drying rate 7.82 to 8.13 percentage of moisture removed per hour produced as a result of increasing the inlet air velocity from 4 to 6 m/s was non-significant. The treatment combinations with air flow rate 1 (6 m/s) were found to have the highest drying rate. Air flow rate 2 (4 m/s) and 3 (2 m/s) showed a significant variation in drying rate.

Similar results were obtained in case of mint drying and the drying rate increased significantly from 6.68 – 8.41% moisture removed per hour with increasing the velocity from 2 m/s to 4 m/s**.** Least square mean of treatment combinations varied from 6.68-8.65% moisture per hour. The treatment combinations with air flow rate 1 (6 m/s) were found to have the highest drying rate. Air flow rate 2 (4 m/s) and 3 (2 m/s) showed a significant variation in drying rate. Temperature was found to vary between 29.5^{0}C to 53.5^{0}C. Highest temperature recorded was at 2 pm. The average temperature developed was used for drying the herb in the drying chamber (Fig 5).

The developed dryer was operated at optimized operational parameters of 3cm bed depth of herb and 4 m/s inlet air velocity and comparative evaluation was conducted compared to drying under no PCM and shade drying.

The time required for reduction in moisture content from 86% to desired 9% -11% in coriander was found lower in case of drying carried out by the developed dryer integrated with PCM. The drying rate values were also higher compared to drying carried out without using PCM and shade drying. In case of the developed dryer with PCM, without PCM and shade drying the overall drying rate was found out to be 7.561%, 3.13% and 2.4%, per hr respectively, the desired moisture reduction from 86 to 10% was completed in 9.5 – 10.2 hr in the developed dryer compared to 24 – 25.2 hr in developed dryer without PCM

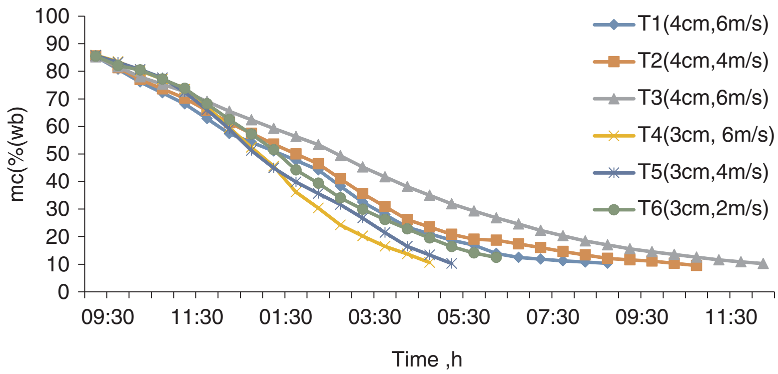

Fig 3 Drying characteristics of coriander.

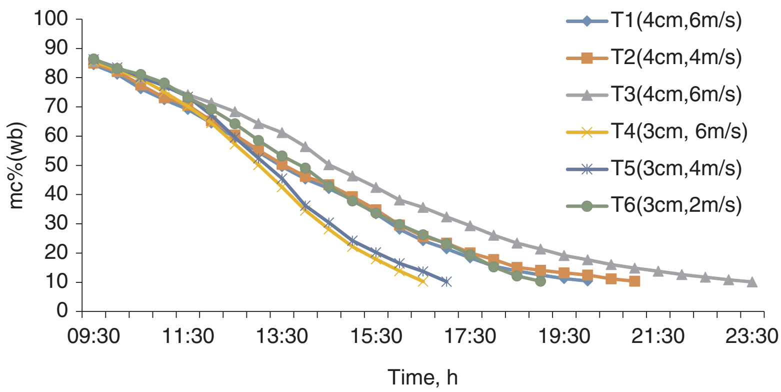

Fig. 4 Drying characteristics of mint.

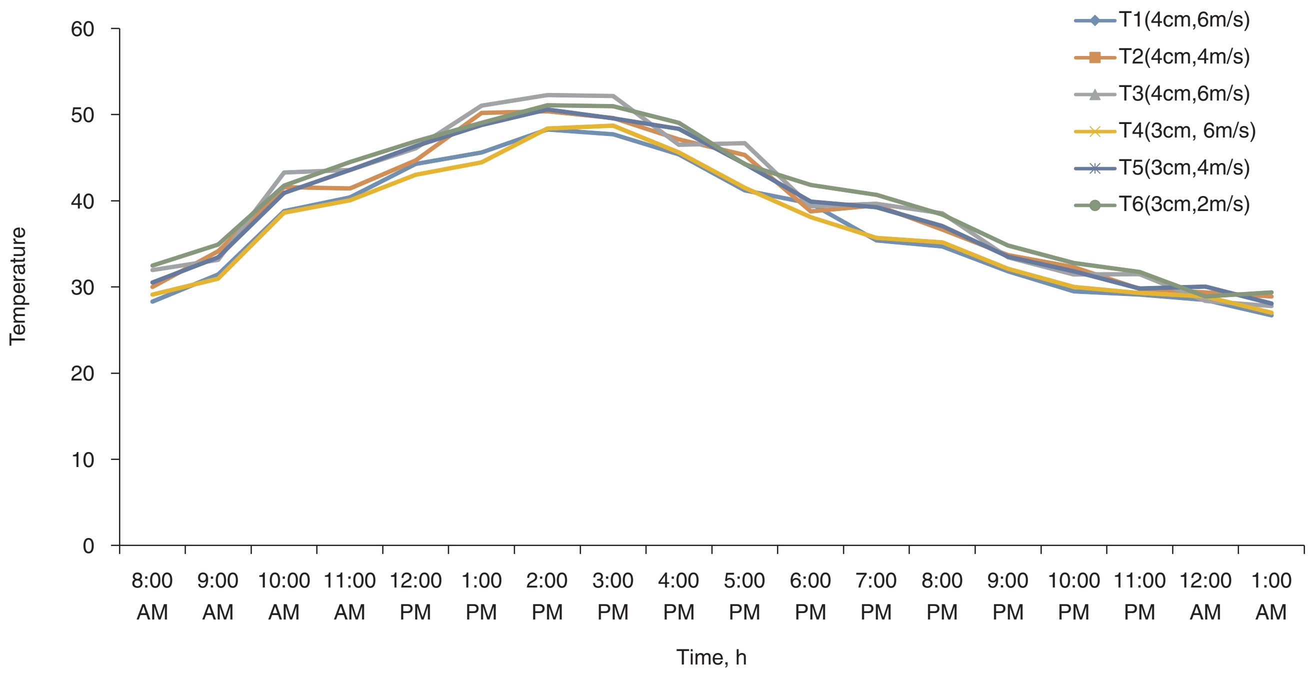

Fig 5 Temperature profiles for various treatment combinations.

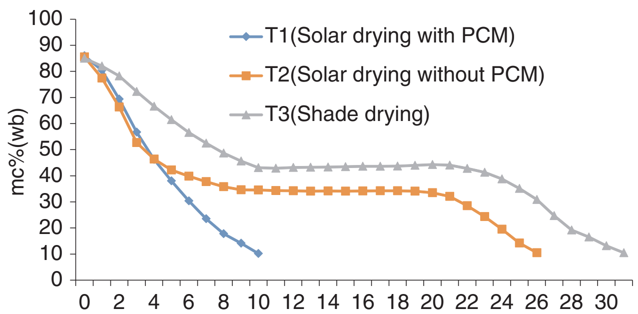

Fig 6 Drying characteristics of coriander under different drying conditions.

and 31- 32 hours in shade drying (Fig 6).

The moisture content was calculated at each 30 minute interval and comparison was made between the developed dryer with PCM, without PCM and shade drying. It was found that the drying rate in the developed dryer with PCM was significantly different (P<0.001) as compared to without PCM and shade drying.

The time required for reduction in moisture content from 84% - 88% to desired 9% -11% in coriander was found lower in case of drying carried out by the developed dryer integrated with PCM. The drying rate values for mint were also higher compared to drying carried out without using PCM and shade drying. In case of the developed dryer with PCM, without PCM and shade drying the overall drying rate ranged from 8.33%, 3.24% and 2.59%, per hr respectively, the desired moisture reduction from 86 to 10% was completed in 8.75– 9.1 hr in the developed dryer with PCM compared to 23.7 – 24.5 hr in developed dryer without PCM and 28.5- 29.5 hr in shade drying (Fig 7). The moisture content for mint was calculated at each 30 min interval and comparison was made between the developed dryer with PCM, without PCM and shade drying. It was found that the drying rate in the developed dryer with PCM was significantly different (P<0.001) as compared to dryer without PCM and shade drying.

The ambient temperature was found to depend on the solar intensity. The highest ambient temperature was recorded between 2 PM and 2:30 PM.The developed solar dryer was tested under no load when using 20 kg of PCM (paraffin wax) as latent heat energy storage material and without using paraffin wax. Before 2 PM the average

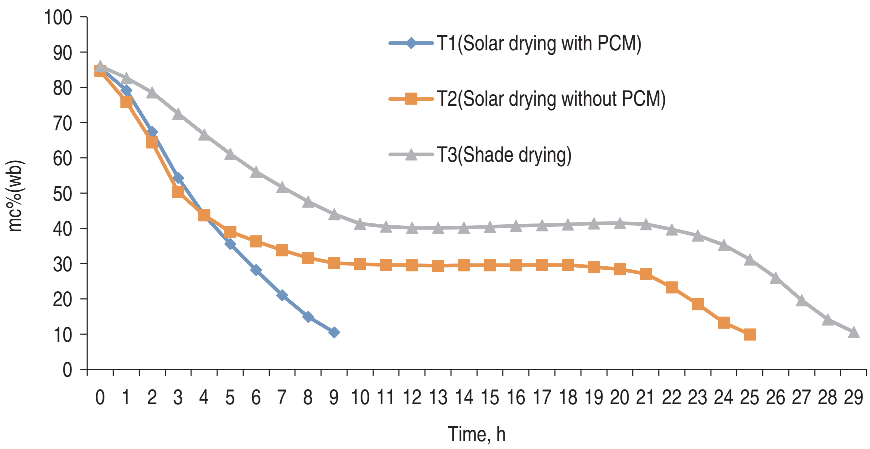

Fig 7 Drying characteristics of mint under different drying conditions.

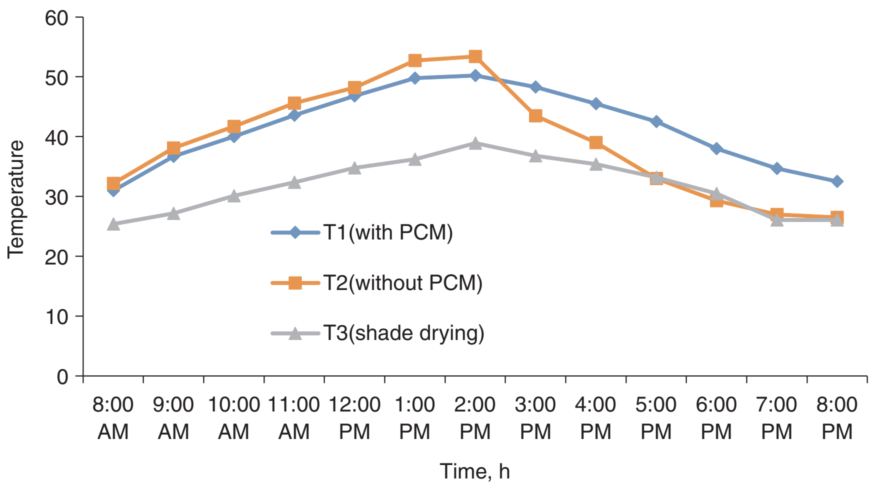

Fig 8 Variation of drying air temperature with or without using PCM and shade drying

temperature of the drying air was almost same but there was slight decrease in temperature when PCM was incorporated due to the part of energy stored in PCM. After 2 PM the temperature decreased apprehensively when PCM was not used (Fig 8).

Drying caused reduction in phenolic content of mint leaves. The results obtained also showed significant differences in phenolic content between fresh mint leaves and dried mint leaves under different drying conditions. It was found that mint dried under solar drying with PCM retains high phenol content 84.15% compared to fresh mint, while the retention of phenolic content was less in case of drying without PCM and shade drying 71.4%, 57.93% respectively (Fig 9).

The results showed that the destruction of flavonoids had varied significant differences between fresh samples and samples dried with different conditions. Flavonoid content in the mint was decreased after drying compared to the fresh mint. Decrease in flavonoid content was least in case of drying using PCM, i.e 28.46%, while decrease in flavonoid content was more in case of drying without PCM (35.03%) and shade drying (52.9%) (Fig 10).

Analysis of variances was conducted at 5% level of significance and it showed a significant difference ($P=0.0004$) in phenol content and ($P<0.0001$) in flavonoid content of the mint dried in the developed dryer compared to the mint dried in the developed dryer without PCM and shade drying.

After drying results in increase in the magnesium and iron content of the coriander herb compared to fresh coriander. The increase in iron content was more in case of solar drying with PCM (90.65%), but increase in iron content was significantly less in solar drying without PCM (89.9%) and shade drying(88.6%). Percentage increase in magnesium content after drying had a significant effect when coriander was dried in the developed dryer with PCM compared to the dryer without PCM and shade drying. Percent increase in magnesium content was 27.64, 21.09 when drying with PCM and without PCM respectively compared to shade drying. Analysis of variances at 5% level of significance. Appendix and Appendix showed that there was a significant difference ($P<0.001$) in both magnesium and iron content of the coriander dried in the developed dryer with PCM compared to the coriander dried in the developed dryer without PCM and shade drying.

Conclusions

Drying rate increased significantly with increase in air velocity from 2 m/s to 4 m/s where as it was not having significant effect on drying rate on further increasing the velocity from 4 m/s to 6 m/s. Increasing the bed depth had a significant effect on the drying rate of both mint and herbs. PCM based solar drying facilitates continuous and uniform drying of the products even 5 to 6 hr after sunshine. The developed dryer facilitates real time moisture measurement by load cells and hence the inaccuracy in measurement of moisture was avoided. The developed dryer with PCM enhanced the drying rate of the coriander by 68.2% and 23.3% in drying without PCM compared to shade drying while in drying of mint, drying rate increases by 68.9%

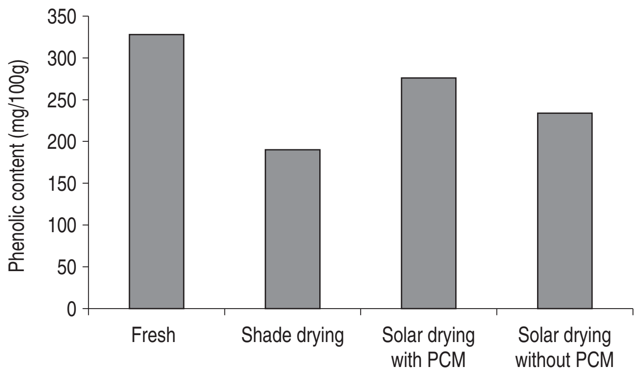

Fig 9 Phenol content retained after drying compared to fresh mint.

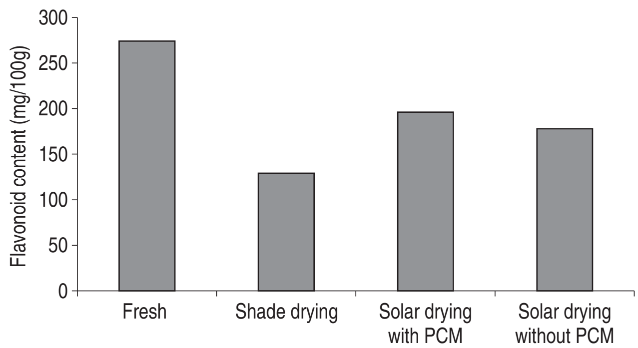

Fig 10 Flavonoid content retained after drying compared to fresh mint.

in drying with PCM and 20.06 % in drying without PCM compared to shade drying. The retention of phenolic content was 31.1% and 18.8% more when mint was dried with PCM and without PCM respectively in comparison to shade drying while retention of flavonoid content was 34.18 % in drying with PCM and 27.52 % when dried without PCM compared to shade drying. The developed PCM based solar dryer provided faster drying rate along with better quality of dried herbs compared to the dryer without PCM and shade drying. This dryer works on solar energy alone thus it may be termed as zero energy dryer without requiring conventional power.

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