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Development of electrically heated dryer for turmeric

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Abstract
India is to be the home of turmeric. It accounts for 80 percent of the world output and 60 percent of world exports. At the time of harvesting, turmeric like all other agricultural commodities, invariably contains high moisture that must be brought down to the desired level at which attack of micro-organisms would be minimized. Post harvest processing of turmeric, generally practiced at rural level, consists of two important processes i.e. curing and drying. At rural level rhizomes are dried by spreading on the floor for open sun drying. Sun drying offers a cheap method of drying but often results in inferior quality of products due to its dependence on weather conditions and vulnerability to the attack of dust, dirt, rains, insects, pests and micro-organism. Farmers often dry harvested turmeric rhizomes to final moisture content in the range of 15-35%, depending upon the weather conditions. Uneven and non uniform drying promotes microbes, especially fungus, to start growth immediately. As a solution to the mentioned issues, a project was planned for developing a tray dryer for drying turmeric rhizomes by electrical energy. The dryer was successfully designed and fabricated with final dimensions of drying chamber - 102 × 53 × 57 cm, drying trays - 100 × 50 × 5 cm with 10 mm perforations and drying chamber stand - 102 × 53 × 70 cm.

Keywords: Electrically heated dryer, moisture content, drying, electric heater, weight reduction, moisture reduction, drying rate, dryer efficiency, physical properties, drying air temperature & RH

1. Introduction
Turmeric is a spice derived from the rhizomes of *Curcuma* longa, which is a member of the ginger family Zingiberaceae. Turmeric is the most ancient medicinal spice, traditionally ubiquitous and held sacred. The history of turmeric is entwined with the history of Indian culture and also with the socio-religious practices of the country. It was popular even in Vedic times because of its unique properties of colour, flavour and also its importance as medicine in Ayurveda, besides its use as a cosmetic and significance in religious ceremonies and auspicious occasions. In medieval Europe, turmeric was known as Indian Saffron, since it was widely used as an alternative to the far more expensive saffron spice. The plant is an herbaceous perennial, 60-90 cm high, with a short stem and tufted leaf. The root or rhizome has a tough brown skin and bright orange flesh. In fresh state, the rootstock has an aromatic and spicy fragrance, which on drying gives way to a more medicinal aroma. The bright yellow colour of turmeric comes mainly from polyphenolic pigments known as curcuminoids. India is to be the home of turmeric. It accounts for 80 percent of the world output and 60 percent of world exports. The main turmeric growing states are Telangana, Andhra Pradesh, Maharashtra, Orissa, Tamilnadu, Karnataka, and West Bengal. Recently, Bihar has started the cultivation of turmeric on a large scale. According to the National Horticultural Board, Bihar produced about 2830 tonnes of turmeric during 2017- 2018. At the time of harvesting, turmeric like all other agricultural commodities, invariably contains high moisture that must be brought down to the desired level at which attack of micro-organisms would be minimized. At the same time, the retention of quality attributes should also be at the maximum. Turmeric contains up to 5 percent essential oils (Ganpati *et al*. 2011) [7] and up to 5 percent curcumin (Tainter *et a*l. 1994) [8]. Post harvest processing of turmeric, generally practiced at rural level, consists of two important processes i.e. curing and drying. The curing operation is carried out with traditional bhatti (oven) which is an inefficient process. The curing of turmeric with traditional methods requires more time and energy. In the traditional method, turmeric is dried under open sun by spreading it on ground or in places that are otherwise unclean, or cow dung smeared floors. Farmers often dry harvested turmeric rhizomes to final moisture content in the range of 15-35%, depending upon the weather conditions.

Uneven and non uniform drying promotes microbes, especially fungus, to start growth immediately. Pruthi (1993) [9] and Jose and Joy (2009) [2] reported that traditional drying methods could result in the loss of volatile oil up (to 25%) by evaporation, and in the destruction of some light sensitive oil constituent. Finally, the dried rhizomes are milled or ground with hand operated *chakki*. Farmers sell turmeric in fresh form. The cost of raw product is comparatively very less as compared to value added product, so value addition at low cost is an alternative to increase income of farmers. At commercial level, the post harvest processing of turmeric involves many unit operations such as washing, cleaning, curing, drying, polishing, size reduction and packaging. Curing is the most important pre-treatment in which cleaned rhizomes are boiled in water; sometimes in addition with 0.1 percent sodium bicarbonate to retain its original colour until the rhizomes are cooked. Cooked rhizomes are cooled first and then dried using commercially available dryers like, tray dryer, cabinet dryer etc. A steady stream of hot air from the electric heater flows into the drying chamber circulating through and over the turmeric resulting in continuous and efficient drying. There was no direct exposure of the turmeric to the environment; turmeric drying was more hygienic as there was no secondary contamination of the products through rain, dust, insects, rodents or birds. The products were dried by hot air only in the drying chamber.

2. Materials and Methods

This chapter deals with the material and methodology adopted for design, and development of an electrically heated dryer for primary processing of turmeric. The research work was carried out to design and develop the electrically heated dryer for turmeric. The electrically heated dryer was designed, fabricated and tested for its performance in actual use. The performance evaluation of the developed system was evaluated at the Department of Processing and Food Engineering, College of Agricultural Engineering, Dr RPCAU, Pusa, Bihar.

2.1 Design of electrically heated dryer

The present research was initiated with the design and development of an electrically heated dryer. The dryer is designed to consist of a drying chamber and electric heater.

The initial design assumptions made for electrically heated dryers are given in Table 1.

The stepwise design calculations of electrically heated dryer are given as below.

2.1.1 Total quantity of water in the product, M_{tw} has been calculated by using following formula

$$M_{tw}=W_t\times M_i/100 \qquad (1)$$

Where,

M_{tw}= Total mass of water in the product, kg

W_t= Mass of the wet product, kg

M_i= Initial moisture content of the product, (% w.b.)

M_{tw}= 25×0.82= 20.5 kg

2.1.2 Bone dry weight of the product, W_{bd}.

It is the dry weight remained after complete removal of moisture from the product, it is calculated by using following formula

$$W_{bd}=W_t - M_{tw} \qquad (2)$$

Where,

W_{bd}=Bone dry weight of product, kg

W_t= Mass of the wet product, kg

M_{tw}= Total mass of the water in the product, kg

W_{bd}=25-20.5 = 4.5 kg

Hence final weight of product at 8% moisture,

$W_f = W_{bd} \times 100/ (100-8) = 5.375$ kg

2.1.3 Mass of the water to be removed during drying, M_w.

Mass of the water to be removed to bring down the final moisture content of the product is calculated with the help of the following formula.

$$M_w=W_t-W_f \qquad (3)$$

Where,

W_f = Final weight of product after drying,

W_t= Weight of the wet product, kg

M_w=25-5.375=19.625 kg

2.1.4 Total energy required for drying, Q_n

$$Q_n= W_{bd}C_p\times (T_d-T_a) +M_{tw}C_w (T_d-T_a) + M_w\times \lambda \qquad (4)$$

Where, Q_n = Total quantity of energy required for drying, kJ

W_{bd}= Mass of the bone dry product, kg

C_p&C_w= Specific heat of product and water, kJ/kg °C.

T_d = Drying air temperature, °C

T_a= Ambient air temperature, °C

M_w =Mass of the water to be removed during drying, kg

λ = Latent heat of vaporization of water, kJ/kg

Q_n = 4.5×0.837× (60-30) +20.5×4.185× (60-30) +19.625×2260

=52141.77 kJ (for 48 hrs) = 1086.287kJ/h

2.1.5 Electric heater capacity

Heater capacity for ideal drying= Total energy required for drying of turmeric

=1086.287/3600 sec

=0.302kw

But for practical purpose assuming dryer efficiency only 25%, Total heater capacity= 0.302/0..25

= 1.208 kw

So an electric heater with a power of 1.5 kw should be selected.

2.1.6 Blower capacity

The amount of energy supplied by air during drying must be

=Amount of energy required for drying of turmeric

So required amount of air (M_a) for drying can be calculated by using following formula

$$M_aC_{Pa}\Delta t=6517.72 \quad \text{or} \qquad (5)$$

$$M_a = 6517.72 / C_{Pa}\Delta t$$

Where,

Ma= Mass of air required for drying,(kg.h^{-1})

Cpa= specific heat of air (1.005 kj/kg)

Δt = temperature difference of air between dryer inlet and outlet

We assume dryer outlet temperature = 45 °C

M_a= 6517.72/ 1.009 × (60 – 45)
= 430.639 kg of dry air per hour
So mass flow rate of air, M_{air} =430.639 / (60×60) = 0.119kg/sec
Now volumetric flow rate of air, V= M/ρ
= (0.119 kg/sec) / (1 kg/m^3) [ρ=1 kg/m^3 for air]
=0.119 m^3/sec
So air blower having volumetric capacity 0.119 m^3/sec should be selected that is
= 0.119 × 3.280843
= 0.3904 cubic feet per second
= 0.3904×60 = 23.62 cfm,
Therefore blower capacity = 23.62 CFM

2.1.7 Dimensions of trays
Considering the loading of turmeric rhizomes as 10 kg/m^2, the total drying area required for 25 kg turmeric was 2.5 m^2.
Considering 5 trays requires 0.5 m^2 for each tray. So the size of each tray was kept as 100 cm × 50 cm with core height of 5 cm.

2.2 Fabrication of electrically heated dryer
Fabrication of the designed electrically heated dryer system was carried out in the following manner.

2.2.1 Dying Chamber
The drying chamber was fabricated as per the conceptualized design. The frame was fabricated with MS angle of 2 mm thickness. From the base to the ceiling of the drying chamber, side rails were provided for stacking five trays evenly at distances of 5cm apart. The entire unit was enclosed in a galvanized iron sheet box and insulated with thermo-coal sheet. The size of the finished drying chamber was 102 × 53 × 57 cm. For loading and unloading of the trays in the drying chamber a door was also provided with locking arrangement. The door was lined with sealing thermo-coal sheet to make it airtight. The inside view of drying chamber is shown in Plate 1.

2.2.2 Trays
Each drying tray (Plate 2) was fabricated as per the dimensions: 100 × 50 × 5 cm with 276 perforations/holes of 10 mm diameter throughout the area of tray (4.33 % of total tray area). Five similar trays were fabricated with food grade perforated aluminum sheet of 2 mm thickness. Each tray carries about 5 kg of the material to be dried.

2.2.3 Drying air inlets
Drying air inlet of 4.8 cm was provided at the bottom of the drying chamber to pass the hot air into it. This air inlet was connected to an electric heater through a 78 cm PVC pipe.

2.2.4 Exhaust air chimney
The exhaust air chimney was fabricated in cylindrical shape with cross sectional diameter of 17 cm and a height of 9.5 cm. It was fabricated with G. I. sheet of 2 mm thickness.

2.2.5 Drying chamber stand
The stand for the drying chamber was fabricated using a 2 mm thick MS angle with size of 102 × 53 × 70 cm. Four heavy duty wheels were provided for easy movement of the drying chamber.

Table 1: Initial design assumptions

	Design parameters	Values
1.	Type of drying product	Pre-treated Turmeric
2.	Initial moisture content (M_i), %	82% (wb)
3.	Final moisture content (M_f), %	08% (wb)
4.	Weight of material (W_g), kg	25 kg
5.	Location	CAE, Pusa, Bihar
6.	Ambient air temperature (T_a), ºC	30 ºC
7.	Ambient air relative humidity (Rh_a), %	76 %
8.	Specific heat of water (C_w), kJ kg^{-1} C^{-1}	4.18 kJ kg^{-1} C^{-1}
9.	Specific heat of ambient air (C_a), kJ kg^{-1} C $^{-1}$	1.005 kJ kg^{-1} C^{-1}
10.	specific heat of turmeric (C_p), kJ kg^{-1} C $^{-1}$	0.837 kJ kg^{-1} C^{-1}
11.	Average drying hours, h	48 h
12.	Drying air temperature (T_h), ºC	60 ºC
13.	Exhaust air temperature (T_e), ºC	45 ºC
14.	Latent heat of vaporization of water (λ), kJ kg^{-1}	2260 kJ kg^{-1}
15.	Efficiency of dryer (η), %	35%
16.	Density of exit air (ρ_e), kg m^{-3}	1.09 kg m^{-3}
17.	Height of chimney (H), cm	10.0 cm

Plate 1: Drying chamber

Plate 2: Tray

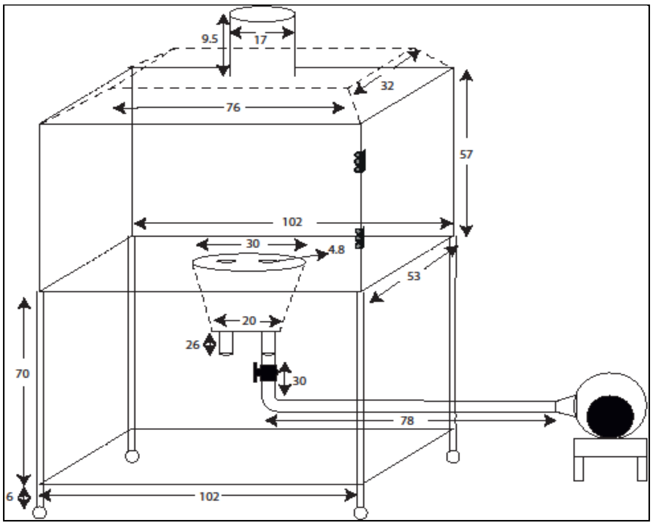

Fig 1: Line diagram of turmeric dryer

3. Results and Discussion

The complete design and fabrication details have been mentioned in chapter II. For the electrical dryer, the air was heated while flowing through spiral type electrical heaters that had a heating capacity of 1.5 kW. The air flow rate was obtained from a centrifugal fan driven by 2900 rpm electric motor. The air which enters the electric heater in such a way is going to come in contact with hot electric coil. As the temperature of the coil is greater than that of the temperature of the air the heat transfer is going to take place from hot electric coil to the cold air. This process of heat transfer is going to increase the temperature of the air. The property of air is such that when the temperature of the air increases, the density of the air is going to decrease and thus the weight of the air is also going to decrease. Thus the lighter air is going to rise to the higher levels. The electric heater is placed at stand to the ground level and other end of the heater is connected to the drying chamber, the hot air is this going to enter the drying chamber. The hot air which is less dense is going to rise through the drying chamber as it enters the drying chamber. Five trays are placed in the drying chamber; these trays are provided with holes which allow the air to pass from the bottom side of the tray to the top side of the tray. Material to be dried has been placed on these trays. The hot air in the drying chamber is going to come in contact with the material surface thus allowing the moisture content in the material to evaporate. As the water is evaporated from the material, the material is going to be dried i.e. it is going to lose the water present in it. Thus the air from the atmosphere is going to take away the moisture from the material and is going to dry it. The drying operation is carried out throughout the day without any interruption. The drying of material takes place without any pollution and without any loss.

4. Summary and Conclusions

India is to be the home of turmeric. It accounts for 80 percent of the world output and 60 percent of world exports. Indian turmeric is considered the best in the world market because of its high curcumin content. India is the largest producer and exporter of turmeric with an annual production of about 931480 tons from 245790 hectares of area with yield of 3790 kg/ha during the year 2018-19 (Anonymous 2019). At the time of harvesting, turmeric like all other agricultural commodities, invariably contains high moisture that must be brought down to the desired level at which attack of micro-organisms would be minimized. At the same time, the retention of quality attributes should also be at the maximum. Post harvest processing of turmeric, generally practiced at rural level, consists of two important processes i.e. curing and drying. The curing operation is carried out with traditional bhatti (oven) which is an inefficient process. The curing of turmeric with traditional methods requires more time and energy. The rhizomes are then spread on the floor for open sun drying. At commercial level, the post harvest processing of turmeric involves many unit operations such as washing, cleaning, curing, drying, polishing, size reduction and packaging.

Sun drying offers a cheap method of drying but often results in inferior quality of products due to its dependence on weather conditions and vulnerability to the attack of dust, dirt, rains, insects, pests and micro-organism. In the traditional method, turmeric is dried under open sun by spreading it on ground or in places that are otherwise unclean, or cow dung smeared floors. Farmers often dry harvested turmeric rhizomes to final moisture content in the range of 15-35%, depending upon the weather conditions. Uneven and non uniform drying promotes microbes, especially fungus, to start growth immediately. Most of the farmers depend upon the weather to dry their produce which results in ineffective drying when it is cloudy or during winter season. On the other hand, conventional fuel operated dryers are costly for rural farmers. As a solution to the mentioned issues, a project was planned for developing a tray dryer for drying turmeric rhizomes by electrical energy. Therefore the attempt has been made to develop a modern technique for drying turmeric with the following objectives:

1. To develop the electrically heated dryer for turmeric.
2. To evaluate the performance of a developed dryer.

The research work was carried out to design and develop the electrically heated dryer for turmeric. The electrically heated dryer was designed, fabricated and tested for its performance in actual use. The performance evaluation of the developed system was evaluated at the Department of Processing and Food Engineering, College of Agricultural Engineering, Dr RPCAU, Pusa, Bihar. The developed system contains a drying chamber with five drying trays, electrical heater, air inlet, and drying air chimney as its components. The performance of the designed system was evaluated under full load conditions.
The specific results of the study are as follows –
The dryer was successfully designed and fabricated with final dimensions of drying chamber - 102 × 53 × 57 cm, drying trays - 100 × 50 × 5 cm with 10 mm perforations and drying chamber stand - 102 × 53 × 70 cm

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