

Comprehensive Review on Drying of Turmeric Rhizomes

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Turmeric (*Curcuma longa L.*) is widely used for its pungent and aromatic flavours and medicinal properties in foods. In the last three years, several studies have witnessed turmeric gaining more economic importance due to its medicinal value against COVID-19. In addition, it has been used for many other medical treatments due to its antimicrobial properties, indicating that it has significant potential in clinical medicine. In view of its importance in the health sector, preserving turmeric is very important to make it available for a longer period. Among the food preservation methods, drying is one of the simplest and oldest methods for increasing the shelf life of agricultural produce. Curcumin is an active ingredient of turmeric, and it is more sensitive to heat and light. Some researchers observed that the direct sunlight, temperature and duration of drying have significant effects on the concentration of curcumin in the turmeric. Open sun and shade drying methods consume a lot of energy and time. In addition, open sun drying samples do not retain maximum curcumin content. Meanwhile, solar dryers provide heat indirectly to the turmeric rhizomes by covering polyethylene sheets or glass. Thus, the turmeric rhizomes are able to dry without losing curcumin content in less time than conventional drying methods. Further, microwave drying, infrared drying, and freeze drying can also be used, but these are not economically feasible for farmers. This paper briefly describes the drying status of turmeric rhizomes in the last two decades.

Keywords: Curcumin, Dehydration, Drying, Rhizomes, Turmeric

Introduction

Turmeric (*Curcuma longa L.*) is a crucial medicinal plant for treating various kinds of diseases in human beings, as it has enormous health benefits.¹ It is also known as 'haldi' in India, which is a popular and sacred spice in the country. India is a leading country in the world's production, consumption and export of turmeric. In 2022–23, India produced 11.61 Lakh tonnes (about 75% of the world's production) in an area of 3.24 lakh hectares of land. Most turmeric is produced in the southern states of India, such as Tamil Nadu, Telangana, Karnataka, and Maharashtra.² Turmeric powder is used as a colouring agent for producing various cosmetics, flavour enhancers in food items, and preservatives in the food industry. Several reports witnessed that the curcumin content reveals various pharmacologic effects such as anti-diabetic, anti-inflammatory, anticancer, anti-HIV, antioxidant, antibacterial, antidepressant activities and protection against hepatic, cardiovascular and neurodegenerative diseases.^{3,4} Turmeric has recently been more valued worldwide due to its special properties against the COVID-19 pandemic.⁵

Drying of agricultural produce is an essential unit operation for storage purpose. It is the oldest and most cost-effective method for preservation of all agricultural produce, and it demands more energy than other unit operations.⁶ Drying of turmeric helps in reduction in water content, thus there will not be growth of fungus and other micro-organisms in the sample, thus shelf life of sample will be increased.⁷ Processing of raw turmeric rhizomes is a challenging task with respect to their final appearance and colour. It consists of three stages: curing, drying, and polishing; after this, it will be converted into powder. The curing process involves cooking fresh rhizomes in water, which helps in uniform drying and gelatinization of starch, distributes pigments uniformly, and increases the drying rate.⁸

According to the United States Food and Drug Administration (USFDA) standards, the final moisture content for whole turmeric is 10% (max) on a wet basis for better shelf life. Hence, after harvesting the turmeric rhizomes, initially, the rhizomes will have 83–87% (wet basis) moisture content, and it needs to be reduced to below 10% to avoid microbial and fungal activity.⁹ Curcumin is an economic content of turmeric, and it is highly

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photosensitive. Further, it is also responsible for the retention of colour and its textural properties. Unfortunately, colour attributes are inversely proportional to the drying rate of turmeric. Thus, turmeric samples should be dried at an optimum drying rate.¹⁰ Enhancement of turmeric quality and complete removal of water activity from it can only be possible by removing moisture content with the help of a suitable drier. Generally, the drying of turmeric under the sun cannot be recommended due to fungal growth during initial drying, lack of hygiene, erratic variation in weather, and finally, it requires much longer drying time to bring the moisture content below 10% with minimum inputs. Keeping the above points in mind, this is an attempt to bring the findings of all experiments together and prepare a brief review from which the researcher can get a better idea of further requirements in the development of drying system for turmeric rhizomes.

Methods of Turmeric Rhizome Drying

Mechanical Drying

Generally, in mechanical dryers, the air is heated by burning various kinds of fuel like wood, petrol, diesel, coal, or electricity, and then the heated air is passed through agricultural produce kept on screens in a thin layer. The heated air will be allowed through the drying samples in order to remove water content from them.¹⁰ The samples will be free from aflatoxin contamination and adulteration in the mechanical driers. Apparently, the labour requirement for drying samples in a mechanical dryer is significantly less than the samples dried under the open sun drying method.⁹ The drying rate can be controlled by adjusting the temperature of hot air circulating through the sample. Further, drying of agricultural produce is possible irrespective of weather conditions/season, day or night. In addition, mechanical dryers are suitable for handling large quantities of herbs/biomass within a short period of harvest. Despite several advantages, it has some disadvantages, such as the need for fuel and mechanical power to drive the blowers. Therefore, the cost of drying is relatively higher compared to the traditional method of drying. Singh *et al.*⁹ cooked the mother and finger rhizomes in an open pan and allowed them to dry using a tray dryer at air temperatures ranging between 45°C to 65°C. In this drying process, the moisture content of the rhizomes was brought to 10% (wb). Results revealed that the mother rhizomes took more drying time than finger

rhizomes. Further, they have reported the optimum drying temperature and air velocity values as 60°C and 2 m/s respectively, to achieve good-quality turmeric. Further, it is also reported that the temperature and flow rate of drying air affect the quality of the agricultural produce.

Khan *et al.*¹⁰ investigated the physicochemical and quality characteristics of turmeric rhizomes under the open sun and hot air drying methods. The turmeric rhizomes were dried in a hot air oven at 60°C, which brought down the moisture content of samples from 82.4 to 9.1% in 3 days. Meanwhile, samples dried using the sun drying method took 29 days to reach a 9.4% moisture content level. It is also reported that samples dried under the sun drying method were found contaminated with aflatoxin B1, whereas there was no contamination in the samples dried in the mechanical dryer. The authors further reported that no microbiological activity is seen in mechanically dried samples, and hence, the quality of turmeric samples dried using the mechanical method is better compared with sun-drying samples.

Gan *et al.*⁸ investigated the drying kinetics of turmeric rhizome using a cabinet dryer (Fig. 1) at three levels of temperatures (40, 50, and 60°C), three levels of blanching timings (5, 15, and 30 minutes) at two levels of relative humidity (20 and 40%) to determine the influence of these factors on retention of curcumin content. The results showed that the maximum curcumin content would be retained when the samples dried at 57°C and blanched for 15 minutes. Further, it is reported that with the increase in drying temperature, there is no adverse effect on the retention of the curcumin content; instead, it shows an increasing trend of curcumin content retention. On top of that, Gagare *et al.*¹¹ witnessed

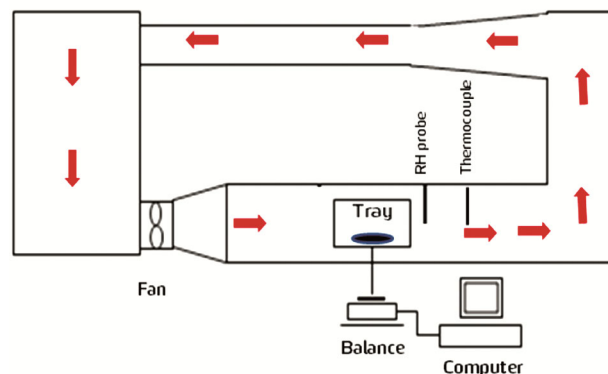


Fig. 1 — Schematic of the laboratory-scale cabinet dryer used in the experiments⁸

that the quality of the turmeric samples cured with 0.1% sodium carbonate solution for 30 min exhibited the best colour uniformity, appearance, and skin removal with the loss of a small amount of curcumin.

Raza *et al.*¹² investigated the effect of different drying treatments, i.e. drying of turmeric rhizomes under the sun, shade, convection oven and hot air oven drying each at four levels of temperature (60, 70, 80, and 90°C) and solar tunnel drying on curcumin content in raw turmeric. The results revealed that the time required for drying turmeric under shade is 76 days and 43 days for sun drying, which yielded minimum curcumin content compared with the samples dried under other methods. In case of the solar tunnel dryer, the water content of samples was brought down below 10% in the span of 37 days, and less curcumin content was yielded than in the dried samples under convection oven and hot air oven drying methods. The longer drying duration under shade and sun drying decreases the curcumin content. Further, it is also reported that boiling turmeric samples in water significantly affects curcumin content. In the turmeric sample, the curcumin content decreases if the boiling time increases and vice versa. It is also reported that the maximum curcumin content has been achieved in the samples boiled for 1 hour and dried under a hot air oven dryer at 70°C drying temperature.

Haryanto *et al.*¹³ studied the influence of drying temperature, the surface area of samples and dry airflow on the drying rate in a tray drier. The tray drier consists of a fan speed controller to control the air velocity, a heat power controller, heaters, a thermometer, a drying chamber, and trays to keep the sample for drying shown in Fig. 2. Results revealed that the drying rate of turmeric rhizome affected significantly by the surface area of the drying sample, velocity and temperature of the air. Further, it is also noticed that the higher the surface area of turmeric rhizomes, the higher the drying rate achieved at the maximum surface area of the turmeric rhizome. The authors achieved the optimum drying air temperature and airflow velocity values as 39°C and 4.5 m/s, respectively, for a surface area of 0.00525 m². Whereas Bezbaruah and Hazarika⁷ reported that the samples with 3 mm thickness displayed a faster drying rate than those with 10 mm thick rhizomes at a drying temperature and airflow velocity of 70°C and 0.85 m/s, respectively.

Solar Drying

Solar drying has become more advanced and economically feasible than other drying techniques. Under this method, the samples will be kept under glass or a polythene sheet in a closed condition. The glass or polythene sheet traps solar radiation; thus, the air becomes hotter than the ambient temperature in a closed chamber. This hot air causes moisture removal from drying samples at a faster rate than open sun or shade drying methods. Several researchers have developed various kinds of solar driers for all agricultural products. This section discusses the solar driers developed for turmeric rhizomes in the following sections.

Jose and Joy⁶ investigated the influence of solar tunnel drying (Fig. 3), conventional drying and commercial drying methods on the percentage of curcumin, volatile oil and oleoresin in turmeric rhizomes. The time required for turmeric drying under traditional drying, conventional drying and solar tunnel drying is about 51 h, 46 h, and 25 h. This shows that the time requirement for drying of turmeric becomes half by the tunnel drying method due to low relative humidity and high temperature. Further, it is also reported that the samples dried under the solar tunnel dryer retained maximum curcumin content compared to those dried under traditional and conventional methods. On top of

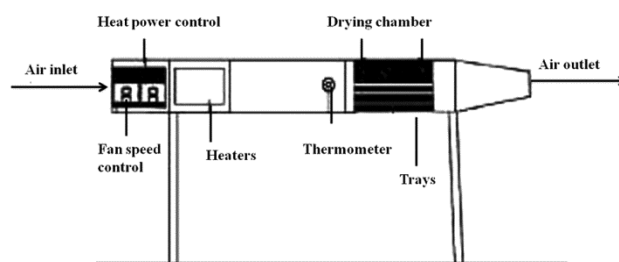


Fig. 2 — Schematic diagram of tray drier¹³

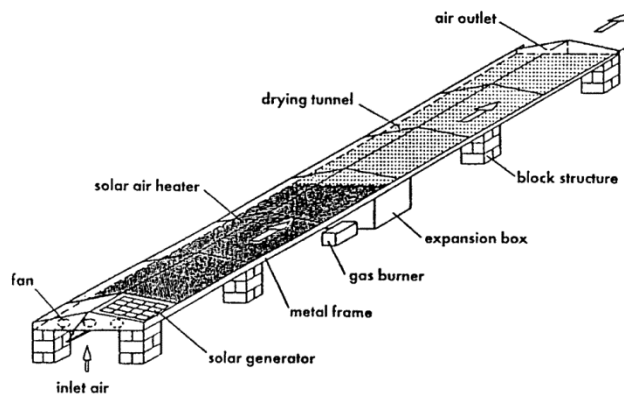


Fig. 3 — Solar tunnel dryer⁶

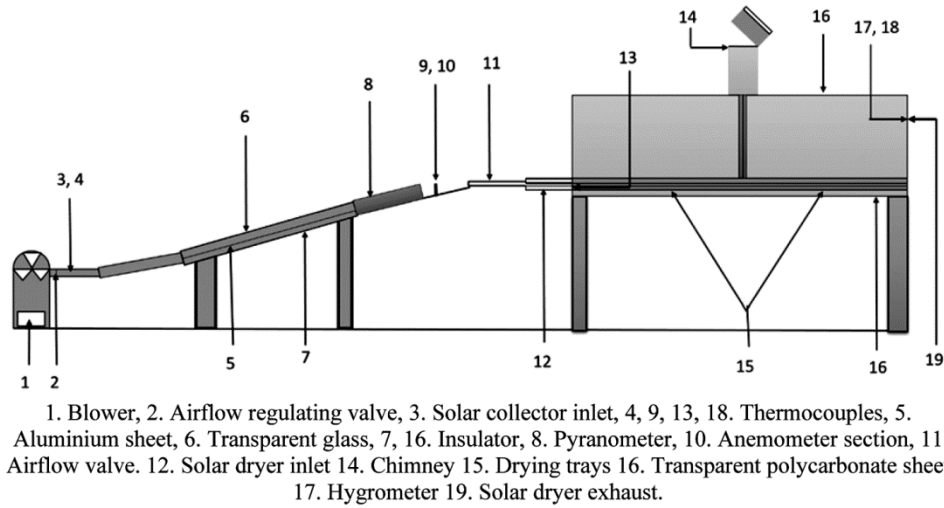


Fig. 4 — Dual-mode solar tunnel dryer setup¹⁴

that, it was also observed that curcumin content in the samples dried under the tunnel drying method yields 5.83%, but under commercial and conventional drying methods, it is reported as 4.40 and 4.64%, respectively. Therefore, the authors noted that the solar drying method is better than conventional and commercial drying methods.

Karthikeyan and Murugavelh¹⁴ studied turmeric drying in a solar tunnel dryer (Fig. 4) from 9 am to 5 pm. They achieved the minimum and maximum air temperatures of the inlet at 42.2 and 82.8°C and those values of the outlet at 40 and 71.8°C, respectively. Further, they also observed that the temperature in the dryer increases with respect to solar radiation. Under this drying equipment, the moisture content of turmeric was able to bring down from 0.779 to 0.070 kg water/kg dry matter within the span of 12 h. Meanwhile, using an open sun drying method took 43 hours. This shows that the time requirement for drying turmeric under a solar tunnel dryer is 3.5 times less than the same under open sun drying.

Borah *et al.*¹⁵ investigated the drying characteristics of turmeric rhizomes in a solar conduction dryer shown in Fig. 5. The drying experiment was conducted for whole and sliced turmeric rhizomes. The dryer utilises solar power in two modes, i.e. conduction and convection. The drying equipment has two portions and a chimney between portions. The dryer also has air vents in the middle of the dryer to provide air circulation. The experiment was conducted from 10 am to 5 pm. The temperature in the drying chamber was observed within 39 – 59°C during the experiments. The dryer was able to bring



Fig. 5 — Solar conduction dryer¹⁵

down the moisture content of the sliced and the whole sample from 78.65% to 5.5% and 6.36% in the span of 12 h, respectively. The results revealed that the drying rate was faster for sliced samples than for solid samples. The authors concluded that the solar conduction dryer could potentially remove maximum moisture content from turmeric rhizomes and eliminate the risk of fungus growth in sliced samples.

Borah *et al.*¹⁶ designed and developed a solar drier for turmeric rhizomes and compared its performance to another drying method. The integrated solar biomass dryer is fabricated with a compound-type parabolic solar collector and sun-tracking system to achieve maximum solar drying time. In addition to this, a detachable husk feeding assembly is also designed and attached with an integrated drying system.

Under an integrated drying system, the moisture content of rhizomes was brought down from 88.19 to $65 \pm 2\%$ (wet basis) with solar drying alone, and then further drying was done using heat produced by firing a biological waste up to the complete removal of the moisture from the rhizomes. The dried samples were compared with the samples dried under four other drying methods: fluidized bed dryer, electric oven, solar integrated dryer, and under the open sun. Further, in all three methods of drying, the authors have maintained the drying temperature around $50 \pm 5^\circ\text{C}$ and sun drying is taken as control. Results revealed that the integrated drying system took six hours less than the open sun drying method to remove the 84.15% moisture content. It was reported that the turmeric samples dried under an integrated drying system required maximum peak force to crush the sample into powder compared to the samples dried under other methods. Further, the maximum variation of color was also observed in the samples dried in the oven, whereas minimum variation was observed in the samples dried in the integrated drying system. Thus, it is concluded that the integrated drying system is safe and ideal for drying turmeric rhizomes as compared with other methods.

Lakshmi *et al.*¹⁷ compared the quality of black turmeric dried in a forced convection solar dryer (Fig. 6) with the samples dried in the open sun drying method. The dryer has two air heaters, thermal energy storage, a heat exchanger, an air blower, and a drying chamber. The air gets heated in the two heaters and will be transferred to the drying chamber through a heat exchanger and blower. The efficiency of solar collectors has been reported at 12 to 42.7%. The authors noted that the samples dried in the mixed mode forced convection solar dryer show better quality attributes in terms of

color, anti-oxidant activity, total phenolic content and total flavonoids than the open sun-dried samples. The developed solar dryer saves 60.7% time compared to the open sun drying method. Thus, the authors have reported that the mix mode dryer would be suitable for drying black turmeric, as the material required to fabricate this dryer is easily available to the farmers.

Kondareddy *et al.*¹⁸ developed a solar dryer (Fig. 7) with the help of locally readily available material for drying black turmeric. The dryer is comprised of an improved solar collector and a chamber for keeping samples. The authors compared the kinetics of thin layer drying of 2 mm turmeric slices in solar, open sun, and tray drying methods. Under thin layer drying, the modified page model described the best drying behavior of turmeric rhizomes with the value of R^2 as 0.9988 and

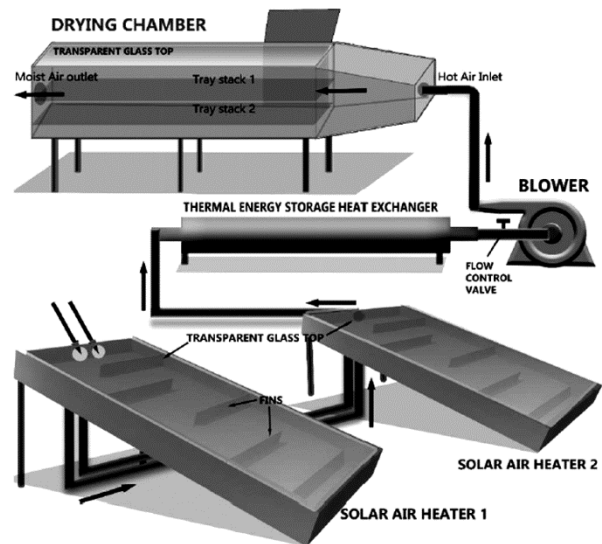


Fig. 6 — Mixed mode forced convection solar dryer with thermal energy storage system¹⁷

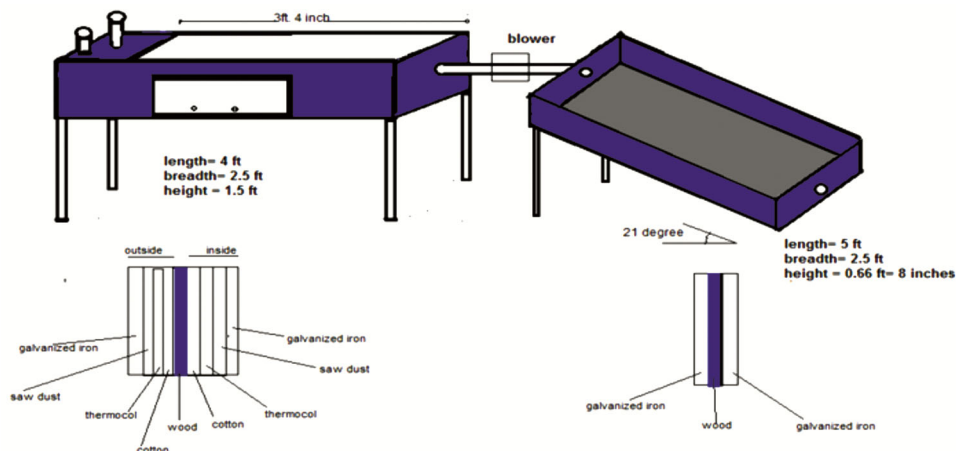


Fig. 7 — Schematic diagram of solar dryer¹⁸

a lower value of χ^2 as 0.0032. Further, it is reported that the color change values of samples dried under a developed solar drier are higher than those dried in the open sun. The authors noted that this low-cost dryer would be better for drying the turmeric rhizomes since it saves significant drying time and minimizes the degradation of dried products.

Prasad *et al.*¹⁹ developed and evaluated the solar biomass integrated drier (Fig. 8) for dehydration of turmeric rhizomes. The drier has two components: a solar drier in which the samples were placed and a biomass burner, where biomass burning will take place to supply the heat during the night. The solar drier consists of single-glazed glass 2 mm thick with an area of 2.12 m² placed on the drier, and to capture maximum solar intensity, the drier is inclined at an angle of 28.5 degrees. The drying equipment has three trays fabricated with a wire mesh base and a total drying area of 0.941 m². Secondly, the biomass burner is fabricated in a rectangular shape box with a dimension of 0.65 m in length, 0.60 m in width and 0.55 m in height. Further, at the bottom of the burner, there is an adjustable door for biomass feeding and to control the airflow for combustion. A chimney is provided at the side of the drier to allow the exhaust gases to go outside. The developed drier can provide continuous hot air of 55 to 60°C. The comparative evaluation of drier with open sun drying is done in terms of the dried rhizomes' quality and the drying time requirement. The results revealed that the developed drier took only 1.5 days to dry the samples compared to 11 days open sun drying. Further, it is also reported that good-quality rhizomes were obtained after drying in the developed drier when compared with the samples dried under the open drying method. The authors concluded that the efficiency of the whole unit is achieved as 28.57%.

Malik and Kumar²⁰ developed and evaluated the solar dryer for thick turmeric (Fig. 9). The developed dryer has been fabricated with a circular-shaped solar collector, a 0.25 × 1.2 m (diameter × height) vertical cylindrical drying chamber made of polycarbonate. The solar collector has two absorbing sheets made of aluminium with a thickness of 1.5 and 1 mm and a 30 mm gap between each other. The solar collector is packed with a thermocol insulation to avoid heat loss at the bottom of the dryer. At the top of the vertical drying chamber, a 12 V DC fan and 2.2 m/s air velocity are fixed to remove the moisture released from the turmeric slices. The dryer gave promising results for drying of 3 mm thick turmeric samples under partial load

condition with higher drying rate and thermal efficiency. Further, the drying rate of the same turmeric samples under forced convection is observed as 42.32 g/h, which is better than natural convection.

Microwave Drying of Turmeric

Microwaves are one of the most used forms of radiation for getting heat with a frequency ranging between 300 MHz and 300 GHz. Long ago, many researchers used microwaves as a heat source for drying food materials, owing to the swift removal of moisture from the food materials.²¹ Microwave penetrates into the moist material, where the microwaves are converted into heat. Thus, the moisture of food material will be converted into vapour and transported into the atmosphere.

In a study²² on the drying kinetics of turmeric in a domestic microwave oven and hot air oven (60°C), the turmeric was dried in the microwave at three levels of power, i.e. 216, 357 and 553 W and two levels of vacuum pressure, i.e. 300 and 400 m-bars. The results showed that under the microwave, the turmeric dried faster than hot air at 60°C. It is also reported that the

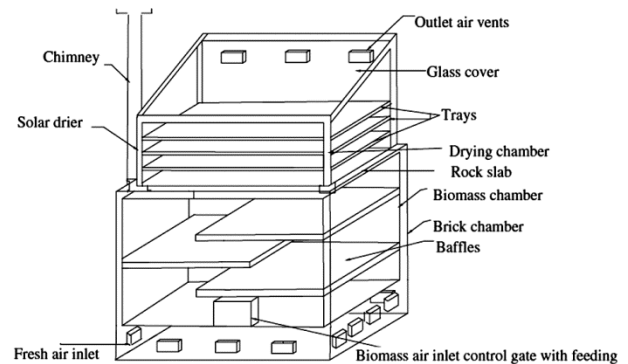


Fig. 8 — Schematic diagram of solar biomass drier¹⁹

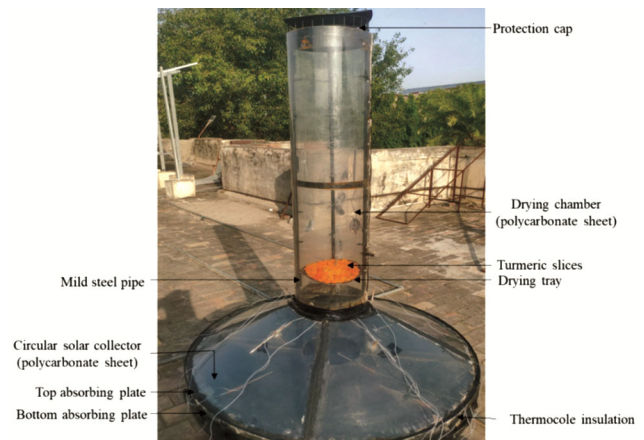


Fig. 9 — Photographic view of partially loaded MVSD²⁰

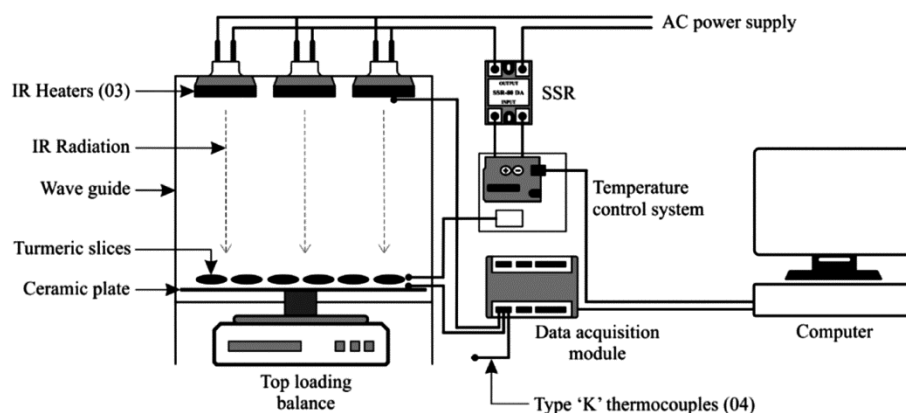


Fig. 10 — Experimental setup for the application of Far-Infrared radiation for drying of turmeric rhizomes²⁴

drying methods significantly affect drying rate, drying coefficients and exponents. The turmeric dried in the microwave gave yellow color, whereas the samples dried in hot air oven gave a darker powder color. Further, Hirun *et al.*²¹ investigated the quality of turmeric at different microwave power levels and the drying time requirement. The authors have reported that the samples dried at a 4000 W power level and drying time of up to 30 min gave good quality turmeric without any color and bioactive compound degradation.

After harvesting turmeric rhizomes, the curing operation before the drying process is a very important postharvest operation that requires the cooking of fresh turmeric rhizomes in boiling water. It is an essential process before the drying operation to avoid raw odour, which destroys the freshness of rhizomes and uniformly coloured products and reduces the drying time requirement. Also, the curing process helps in the development of attractive colours and characteristics of aromas. Hence, Gagare *et al.*¹¹ reported that the turmeric samples cured for 30 min yielded better quality in terms of colour uniformity, appearance and skin removal and 1.5 kW power is optimum for drying turmeric rhizomes. Contradictorily, Surendhar *et al.*²³ reported that the curing process shows a negligible or negative effect on the quality of samples dried under microwave methods, and hence, they convey the message that there is no necessity to go for the curing process.

In another study²³ with the microwave drying method, the samples were dried at four power levels (30, 50, 80, and 100% power) with a total output of 900W. The authors reported that the samples dried under the microwave were better than those dried under the conventional method of drying. Further, they have reported that the fresh and cured slice has similar drying characteristics and energy analysis; the

quality of fresh samples is better than that of cured samples.

Infrared Drying of Turmeric

Fernando *et al.*²⁴ investigated the effect of exposition of different wavelengths (6.65, 5.97, 4.97, and 4.80 μm) of far-infrared radiation (FIR) for different exposure times (70, 30, 25, and 20 min, respectively) on drying characteristics and process parameters of turmeric rhizomes. The experimental setup of this study is shown in Fig. 10. The results revealed that the optimum far-infrared radiation and exposure time were observed as 5.51 μm and 21 min, respectively. The authors concluded that the far-infrared radiation would be effectively suitable for the dehydration of turmeric rhizomes.

Jeevarathinam *et al.*²⁵ reported that the samples dried in infrared assisted with hot air had retained maximum curcumin, oleoresin, and starch content at a drying temperature of 60°C when compared with the samples dried in infrared drying and hot air drying methods. Further, it is also reported that the colour deterioration of the samples dried in the infrared-assisted dryer is significantly less than that of those dried in the remaining two methods. Finally, the authors suggested that infrared assisted with hot air drying at 60°C is better for achieving good quality turmeric rhizomes.

Conclusions

To enhance the shelf life of turmeric rhizomes and to avoid microbial activity, bringing of water content below 10% through a suitable dryer and application of appropriate processing technology is very much essential. Drying turmeric rhizomes to desired moisture content levels with low input energy without losing curcumin content is a challenging task. Meanwhile, it is concluded that drying of turmeric rhizomes through microwave is faster than drying through solar drying,

followed by infrared assisted with hot air drying at 60°C, hot air oven drying, sun drying and shade drying. A drying temperature of 60 to 70°C is the optimum temperature to achieve maximum drying rate without losing curcumin, oleoresin and starch content. Fresh and cured rhizomes have similar drying characteristics. Moreover, fresh samples yielded better quality rhizomes than cured rhizomes after the drying process was done in the microwave. Currently, no equipment is available for drying turmeric on a large scale, i.e. for farmers' fields. Hence, the development of suitable dryers is needed for the dehydration of turmeric on a large scale.

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