Solar Dryer Integrated with Thermal Energy Storage Systems for the Preparation of Dry Grapes in the Farmyard: Sustainable Rural Farming Approach

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Abstract
India is one among the top countries in the production of dried grapes to the total annual rate of production about 230,000 tones. Grape is an important commercial fruit crops grown in India to a total area of about 117.6 thousand hectares with an annual production of 24.831 lakh million tones. Grapes were usually converted into raisins (partially dried grape) for its edible and medicinal values and also to retain its quality for exporting and other purposes. The cost of the raisins that sold in markets are so high all because of its production processes that it goes through, though these raisins are well known for its medical values with added taste, people where still struggling to use this product though the rate of production of grape is high.

Hence this work attempts to lower the cost of raisin production using solar energy for drying. The quality of raisin totally depends on the way they processed and dehydrated, which requires permanent heat supply. To improve the quality of heating process thermal storage devices using phase change material (PCM) is established. Their performance and reduction in power consumption is evaluated with conventional electric heater.

Keywords: Raisins, grapes, solar energy, phase changing material.

Introduction

Grape (*Vitis venifera*) is an important commercial food crop in India; Grape growing has been regarded as most remunerative enterprise. Grape is cultivated around an area of about 117.6 thousand hectares with production of 24.831 lakhs million tones [1]. Grape cultivation is more in the states of Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu. It is being cultivated in North Indian states as temperate crop. In Tamil Nadu especially in Madurai and its surrounding areas for its tropical climate, the grape is cultivated throughout the year through staggered pruning [2].

Grape can be eaten fresh as table grapes or it can be used for making wine, jam, grape juice, jelly, grape seed extract, raisin, and vinegar and grapes seed oil. Grapes are non climacteric type of fruit, generally occurring in clusters. One cup (151 grams) of grapes contains the following nutrients calories 104, carbohydrates 27.3 grams, protein 1.1 grams, fat 0.2 grams, fiber 1.4 grams, vitamin C 27% of the Reference Daily Intake (RDI), Vitamin K 28% of the RDI, Thiamine: 7% of the RDI, Riboflavin 6% of the RDI, Vitamin B6, 6% of the RDI, Potassium 8% of the RDI, Copper 10% of the RDI and Manganese 5% of the RDI. It also acts as a powerful antioxidant necessary for connective tissue health. Though they contain sugar, they have a low glycemic index and don't appear to raise blood sugar levels. Antioxidants in red grapes mainly resveratrol, reduce inflammation and helps to protect against cancer, heart disease and diabetes [3].

Grapes are easy to incorporate into the diet. The major consumption of grapes in India is as fresh followed by raisins, wine and juice. While at global level 70-80% of grapes are processed into wine followed by raisins and juice [4].

Fresh grapes have high moisture and sugar content which are very sensitive to microbial spoilage during storage, even at refrigerated conditions which contribute to quality loss [5]. Drying removes moisture content to a very low level and drastically reduces microbial, enzymatic degradation or any moisture-mediated deteriorative reactions.

In addition, drying results in some benefits such as substantial reduction in weight and volume, minimizing packing, storage, and transportation costs [6]. Drying is one of the most frequently used methods for grapes processing. It can process grapes into raisins for longer shelf-life as well as dehydrated grapes, which can be used for wine or juice production. Rate of drying is very important to get assured quality. There are two zones in rate of drying namely constant rate drying and falling rate drying. Constant rate drying occurs whenever the product is very thin and diffusion of moisture through pores is not controlling. Falling rate, on the other hand results whenever the diffusion through pores is controlled. Falling rate drying predominates during drying most of the products [7].

The drying methods include the traditional open sun drying, shade drying, hot-air drying, freezing drying, microwave drying, as well as the vacuum impulse drying [8]. Although the investments and operation of natural sun drying is small and simplicity, it has several drawbacks such as it requires long drying time usually more than 2-3 weeks, rewetting of products caused by bad weather, contamination due to dust and insects, tedious and laborious to make the product more uniform and nutrients deterioration when exposed to solar radiation for long time [9]. Other than sun drying and shade drying remaining processes involves higher investment and operating cost that drastically hike the cost of raisin in order to eliminate this phenomenon a sustainable method of raisin production with solar dryer is utilized to maximize the use of natural sun light. The solar dryer performance mainly depends upon the climatic conditions, humidity level and availability of sunlight and also the intensity of solar radiation of that particular area where it is constructed. Since the efficiency of the raisin production highly depends on its uniform temperature heating, an experimental study is carried out in solar dryer integrated with thermal storage medium to analyze the efficiency improvement in solar dryer.

A thermal energy storage medium must meet the requirements of a stable storage material with high heat capacity. Heat storage based on the sensible heating of media such as water, rock, and earth represents the first generation of solar energy storage subsystems.

However, recently the heat storage based on the latent heat associated with a change in phase of a material offers many advantages over sensible heat storage. PCM's are ideal because the latent heat associated with melting and freezing is capable of storing much more heat than sensible thermal storage alone[10].

When the heat generating component is on, the PCM tends to liquefy at certain temperature for passively storing the heat. Once the heat generating component is shut-off the PCM will begin to solidify by releasing the stored energy. In this study, Granules and paraffin wax is selected as thermal storage medium for sensible heat and latent heat storage respectively for drying grapes.

Experimentation

Conventional Method of Drying Grapes: Mechanical drying has been widely used in raisin production due to its rapid, controllable, low labor, and high quality of products[11]. The grapes are dried in hot air oven a mechanical dryer as is shown in Fig 1. The readings are taken at an interval of one hour and the results are tabulated as shown in the table 1.

- Initial weight of sample 1= 48.958g
- Initial weight of sample 2= 45.815g

Table 1
Hot air oven (conventional dryer)

S.N.	Sample 1		Sample 2	
	Temperature (°C)	Weight (g)	Temperature (°C)	Weight (g)
1	50	48.958	50	45.815
2	55	46.650	55	43.242
3	60	45.507	60	41.678
4	65	43.697	65	39.372
5	70	39.354	70	34.507
6	75	32.526	75	27.953
7	80	29.867	80	24.577
8	85	20.661	85	17.243
9	90	17.637	90	9.098

Fig. 1: Hot air oven

The dried grapes sample is shown in the Fig 2. Optimization of hot air oven temperature for drying the grapes, it is noted that the temperature range from 55°C to 70°C the outcome of the raisin quality is good and this temperature can be achieved by the solar green house dryer.

Solar Dryer for Drying the Grapes: Solar dryer is considered as the economical tool for drying agricultural products because of increase in fuel prices and depletion of fossil fuels. The solar radiation reaches the dryer depends on the sunshine hours, climate, weather, atmospheric clearness and location [12]. Even though it has many criteria to be considered, it acts as a perfect substitute for fuel based dryers. The grapes are dried in solar green house dryer, initial and final weight of the grapes is measured and the results are noted in table 2.

- Initial weight of the sample = 180 g
- Average solar irradiance of the month (November) = 3.46 kw/m^2/day
- Latitude: 10.35°
- Longitude: 77.95°

Solar Dryer with Thermal Storage System: Though solar dryer utilize solar energy which is renewable, free and an environment friendly, it has limitation such as sunshine hours and weather change. In order to overcome the climatic, weather factors and also to extend the usage of solar dryer beyond the sunshine hours to achieve the constant drying rate in raisin production, thermal storage system is used. Paraffin wax and granules are used as thermal storage system to improve the system efficiency. The dryer used for the preparation of raisin is pictured in fig 3.

Characterization of phase change material: Paraffin is selected as phase change material for a latent heat thermal energy storage system. Paraffin is heated at 60°C, about an hour.

Then heated paraffin wax is kept in contact with water to measure heat transfer rate. Melted paraffin wax transfers the heat to water and solidifies. Temperature of water and paraffin was measured in data logger using thermocouple.

Table 2
Solar greenhouse dryer

Day	Average temperature (°C)		Initial Sample weight (g)	Final sample weight (g)	Weight difference (g)
	Minimum temp	Maximum temp			
1	36	42	180	162	20
2	38	44	162	144	22
3	30	35	144	138	6
4	34	40	138	124	14
5	31	37	124	116	8
6	33	37	116	110	6
7	34	40	110	98	12

Fig. 2: Dried grapes sample

The rate of heat transfer from paraffin to water is shown in Fig 4. From the Fig 4 it is observed that the paraffin has good latent heat storage capacity and high rate of heat transfer. Data logger used for getting the above reading is given in the fig. 5. Thus the graph itself shows that using paraffin (Phase Changing Material) as a thermal storage medium in solar green house dryer will surely improves the efficiency of the dryer by maintain the temperature nearly constant irrespective of the temperature outside.

Results and Discussion

With reference to the Table 1 it is noted that the temperature of 55ºC to 60ºC will give a better quality dried grapes within a day of drying time, whereas this temperature of 50 to 60 can also be attained by the solar dryer, so it seems that usage of solar dryer is so economical than using conventional dryer. The only drawback in this system is this will heat the grape only when the sun is available, the solar green house dryer takes about six days to dry grapes using minimum sunlight.

Fig. 3: Solar green house dryer

Fig. 4: Data logger used for estimating the paraffin characteristics

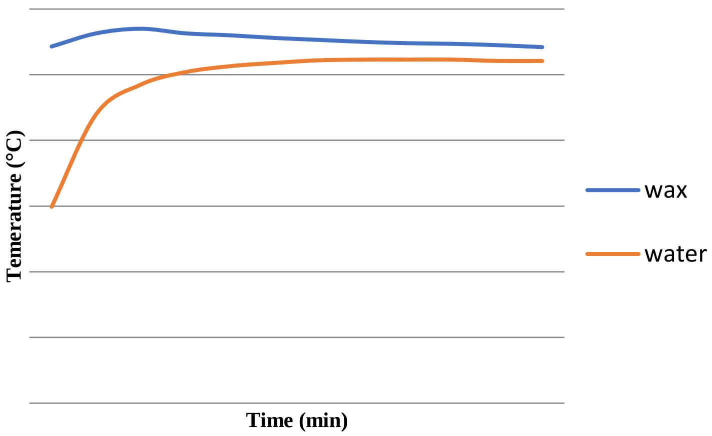

Fig. 5: Heat Transfer Rate

From our observation regarding these two we conclude that usage of thermal storage system would greatly improves the system efficiency and performance. Paraffin, a latent heat storage medium is experimented under laboratory conditions to test its performance regarding thermal storage and librating back when needed, from that it is found that paraffin tends to liquid at a temperature of 60°C and when it came in contact with the water it tends to transfer the heat rapidly to bring the water temperature nearly equal.

So, if this PCM (phase changing material) is used for drying grapes it would surely give a better result. Even during low or no sun shine period this PCM material can be heated using conventional heater, so that instead of using conventional hot air oven this would improves the performance with low energy supply and even no energy supply during bright sunny days.

This whole project is carried under low sunlight and raining period and it is noted that even at a very low sunlight this dryer give a better output and incorporating this with thermal storage medium would surely increase its performance and it can be commercialized for large scale raisin productions.

Conclusion

Grape is one of the most important commercial food crop grown mostly in southern parts of India. In India most of the areas where grapes cultivation is still in domestic scale and the farmers who cultivating this only follow the traditional way of drying the grapes for raisin production (open sun light drying), this was the main reason that India is still lagging in global market in standard quality raisin production.

Usage of hot air dryer for drying the grapes is cost wise too high for them to afford, so by introducing solar green house dryer for drying the grapes would surely result in the production of better quality of grapes. In addition to overcome the drawback of solar green house dryer that is its climate and temperature dependent. We used Paraffin a thermal storage device which is cost wise too low and it also gives better performance output.

Form the above findings and discussion we concluded that usage of solar dryer integrated with thermal storage medium would surely improves the quality of dried grapes production in added that this will resist the climate and other draw backs that we seen in conventional solar dryer system.

By evaluating this system performance, it is concluded that this system would work better for domestic level applications and further improvement of this system is need for commercialization of dried grapes production.

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