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Research Article

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Development of Polyhouse Solar Dryer for Drying Granular Jaggery

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Abstract

Jaggery is a traditional Indian sweetener prepared from sugarcane juice through evaporation process and is considered as medicinal sugar due to its nutritional and thereupatic properties. To improve the shelf-life of solid jaggery , making jaggery in the form of granules with moisture content of 1–2% was recommended. A Polyhouse solar dryer for drying granular jaggery with a capacity of 200 kg was developed at Regional Agricultural Research Station, Anakapalle, Andhra Pradesh, India. Traditionally, granular jaggery was dried in openyard resulting in contamination with dust, insects, birds and rain. A comparative study was carried for drying granular jaggery with initial moisture of 9.3 to 10.5% (db) in both polyhouse solar dryer and in an open yard during the month of March–April, 2019. The study revealed that the rate of drying was faster in poly house compared to open yard drying. The temperature inside the polyhouse dryer was 59% higher than the ambient conditions. The percent saving in time for drying of granular jaggery in poly house dryer was 38% to attain optimum moisture content of 1.7% for stable shelf life besides maintaining hygienic conditions. The quality parameters of jaggery in terms of sucrose and reducing sugars percentage showed insignificant changes in both methods. However, the color of the granular jaggery was well retained in polyhouse dryer compared to open yard drying. Hence, this study will be helpful for small and micro entrepreneurs for large scale drying of granular jaggery under hygienic conditions utilizing renewable energy resources.

Keywords: Granular jaggery, open yard drying, polyhouse, quality analysis

1. Introduction

Jaggery was known to be a traditional sweetener in India since age-old and is prepared by concentration of sugarcane juice . India occupies lion's share in production, consumption, and export of jaggery, producing about 60% of the world's production (Varma et al., 2019). Jaggery is a store house of minerals that crowns it as healthier sugar, with sucrose (65–85%), reducing sugar including glucose and fructose (10–15%), non-sugars such as calcium (0.4%), magnesium and phosphorus (0.045%), protein (0.25%) and fat (0.05%) (Pandraju et al., 2021). Jaggery serves several health benefits such as improves immune system , helps in overcoming cold and to women during menstruation (Prasad and Shivay, 2020). Normally, jaggery is available either in solid blocks or liquid form. However, the shelf-life of solid jaggery is very limited and gets spoiled easily due to the microbial contamination making it unfit for consumption. Especially

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in the coastal regions of Andhra Pradesh, where the relative humidity is very high, maintaining the quality of jaggery is a major problem. The inherent moisture content present in the jaggery at the time of preparation highly affects the keeping quality of jaggery. To extend the shelf life, jaggery making in granular form was introduced which has substantial market value and commercial importance.

Granular Jaggery making process consists of various unit operations viz. cane juice extraction, clarification, concentration by boiling, cooling, shearing into a granular , drying, packaging and storage. Of all these operations, drying operation plays a vital role in safe storage. It was reported that every year about 10% of jaggery produced in India was lost due to moisture deterioration accounting to a worth of about $0.6 million (Mandal et al., 2006). Hence, Drying of jaggery below 2% is highly essential which can be done under controlled drying system instead of depending on weather conditions. Granular jaggery needs to maintain the optimum moisture content to meet the standards for hygienic handling, packaging, transportation and storage. The freshly prepared granular jaggery consists of 8-10% moisture and has to be dried to 1–2% mc (db%) and should be packed into moisture proof polyethylene-polyester laminates and PET bottles Jaggery made in powder form is usually sun-dried to increase its shelf life and facilitate its long-term storage (Varma et al., 2019). Traditional sun drying in the open yard causes contamination with dust, impurities and birds' excreta and is labourious with time-consumption. Though sun drying of crop produce is economical, but the product obtained is of lower quality due to contamination by dust, insects, birds, pets and rain (Varma et al., 2020). Mechanical drying of granular jaggery is costlier in terms of capital investment and operation cost. The use of solar energy can be an alternative for drying granular jaggery on a large scale as it prices low and facilitates easy availability. Prakash et al. (2014) reported that solar poly house tunnel dryer is effective in drying vegetables and fruits with saving time up to 50–70%. Drying of solid jaggery was attempted in Green house by natural and forced convection to predict the rate of moisture evaporation by applying Fuzzy logic software (Prakash et al., 2015). The predicted values are validated with experimental values and reported absolutely low error values. Raj et al., 2021 have designed a tunnel dryer for drying of one tonne of solid jaggery with a length, height and width of 18, 1.2 and 1 m respectively and evaluated drying time of 68 minutes. It was reported that solar dryers are faster, more efficient, and more hygienic, resulting in lower crop losses relative to the traditional open-air sun drying method (Tomar et al., 2017).

Keeping in view of the above facts and to have a hygienic and fast drying of granular jaggery without affecting its quality, a polyhouse type solar dryer was developed at Regional Agricultural Research Station, Anakapalle. The study was taken up to evaluate the drying efficiency of polyhouse solar dryer and compared with open yard sun drying for freshly prepared granular jaggery so as to recommend for small scale jaggery farmers and entrepreneurs.

2. Materials and Methods

A polyhouse type solar dryer with a capacity of 200 kg was designed and installed at Regional Agricultural Research Station, Anakapalle, Andhra Pradesh, India during the month of March–April, 2019. Granular jaggery was prepared from the sugarcane Var 93 A 145 as given in the flow chart (Figure 1). The drying studies were conducted with freshly prepared granular jaggery in both polyhouse dryer and open yard drying. The freshly prepared granular jaggery was spread uniformly in the trays at 15 mm thickness. Drying was carried out for 6 hours a day.

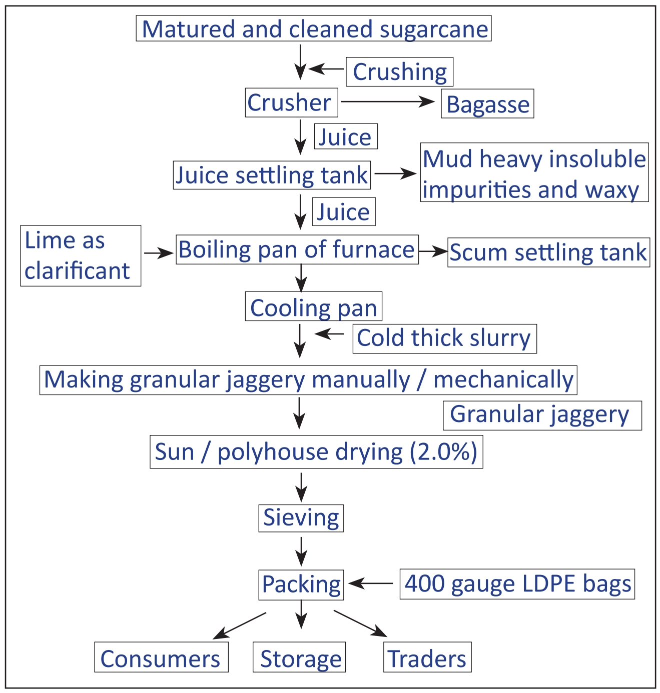

Figure 1: Flow chart for granular jaggery making

2.1. Design of polyhouse dryer

The polyhouse dryer consists of an arch type collapsible iron frame structure with one tier to place aluminum trays. Based on the bulk density of granular jaggery, the surface area required to load granular jaggery (200 kg) was calculated as 26 m^2. An arch type polyhouse dryer of 12×2.7×2.7 m^3 (L×B×H) was designed and one tier frame structure was fabricated inside the chamber to hold 40 aluminum trays of size (0.9×0.6×0.075 m^3) for drying of granular jaggery. Freshly prepared granular jaggery was spread over the trays at 15 mm thickness for uniform drying. The design specifications of the solar polyhouse dryer for drying 200 kg of granular jaggery was given in Table 1. The polyhouse dryer was installed with the leaning side of the arch facing North-South to entrap maximum solar radiation (Figure 2). The UV stabilized cross laminated semi-transparent polyethene sheet (150 gsm) is used to cover the frame and to retain radiation inside the

Table 1: Design parameters and specifications of solar poly house dryer for drying granular jaggery

Sl. No.	Component	Specification
1.	Initial moisture content	10–12% (db)
2.	Final moisture content	1–2% (db)
3.	Proposed thickness of jaggery in the trays	0.015 m
4.	Bulk density of granular jaggery	500–550 kg m^{-3}
5.	Capacity of dryer	200 kg
6.	Overall size of the dryer	12×2.7×2.7 m^3
7.	Walkway size	12×0.9 m^2
8.	Size of aluminum trays	0.9×0.6×0.075 m^3
9.	Total no. of trays	40
10.	Total area of aluminum trays	21.6 m^2
11.	Total no. of ventilators	12
12.	Each ventilator size	0.6×0.3 m^2
13.	Top chimney ventilators	2 no.
14.	Exhaust fans 0.25 hp each	2 no.

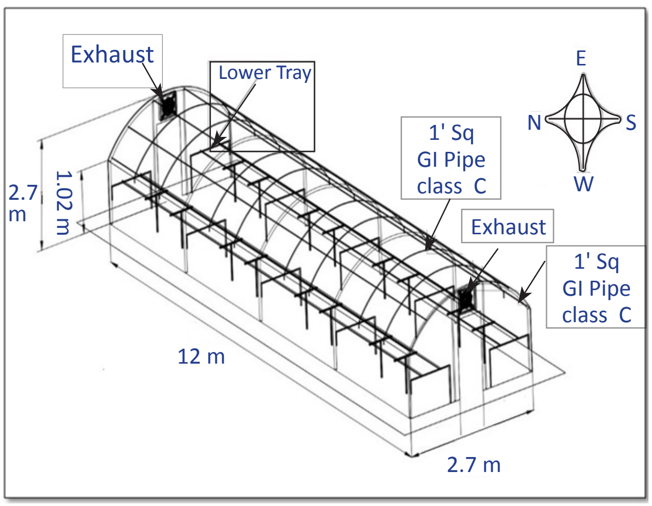

Figure 2: Schematic representation of the polyhouse type solar dryer

dryer. The polyhouse dryer was provided with two exhaust fans at the top near the front and rear side for enhancing air circulation to obtain a higher drying rate. Twelve ventilators were provided to create natural convection for the removal of moist air out of the poly house. The polyhouse dryer was installed with temperature and humidity measuring devices to measure the temperature and humidity on an hourly basis.

2.2. Performance evaluation of polyhouse dryer

The drying in poly house solar dryer depends on outside climatic conditions especially temperature and humidity. The temperature and relative humidity inside the polyhouse dryer were recorded using digital thermo-hygrometer (Temperature range: -50 to 70°C, humidity range: 10–99%) on an hourly interval from 10 am to 4.00 pm. Similarly, outside air temperature was measured at the same time under ambient conditions. The granular jaggery was loaded fully in all trays and the efficacy of the dryer was tested under full load conditions. The simultaneously same quantity of granular jaggery was placed in aluminum trays in 0.015 m thickness and allowed to dry under an open yard (Figure 3).

Figure 3: Drying of granular jaggery in polyhouse and open yard

2.3. Quality analysis

The quality of granular jaggery dried in poly house dryer and open yard drying were evaluated in terms of sucrose percentage, reducing sugars percentage, moisture content (percentage db) and color.

2.3.1. Determination of moisture content

The moisture content of granular jaggery before and after drying was calculated by the Gravimetric method as per Anonymous (1990) and expressed as a percentage dry basis.

2.3.2. Measurement of color

The color of the jaggery was measured using a portable colorimeter (Model: Spectro-guide 45/0 gloss; Make: BYK Gardner, Geretsried, Germany) calibrated against a white and black tile. The values of L^*, a^* and b^* were taken at three locations in the jaggery sample and their average was noted (Coyago-Cruz et al., 2019) . The color of the sample is expressed in the CIE scale (*Commission Internationale de I'Echairages*) in terms of L^*, a^* and b^*, where L^* denotes lightness, a^* indicates red/green value and b^* denotes yellow/blue value.

2.3.3. Estimation of sucrose and reducing sugars

The percent sucrose of jaggery samples was recorded using a polarimeter (Antanpaar, Model: MCP 500 Sucromat). The percent reducing sugars are estimated by Lane and Eynon method (Anonymous, 1965) using and Fehlings A and Fehlings B solutions.

3. Results and Discussion

3.1. Drying characteristics of granular jaggery in polyhouse

Granular jaggery was placed in trays with a thickness of 15 mm and dried in polyhousedryer and open yard drying. In polyhouse, the maximum temperature of 51°C was recorded whereas under open yard drying it was 32°C. Hence, there is a 59% rise in temperature inside the polyhouse dryer. The highest relative humidity (RH) recorded inside the polyhouse dryer was 59% as compared to 77% RH outside. In Polyhouse, the low relative humidity with high temperature enhanced the rate of drying which are similar to results reported by Shahi et al. (2011). It was already reported the critical humidity for storage of jaggery should be less than 69% RH to minimize physicochemical changes and microbial growth which was maintained in polyhouse dryer under study (Varma et al., 2020). In solar drying of products, vapourization of moisture takes place by thermal heating resulting in removal of moisture. Solar drying is accompanied with simultaneous heat and mass transfer (Prakash et al., 2015). The heat energy is transferred from two sources namely surrounding air and from sun to the jaggery surface in diffrerent heat transfer modes. Some part of this energy vapourizers the moisture present inside the jaggery through Latent heat of vapourization and the remaining amount is being utilized to increase the jaggery surface temperature in the form of sensible heat. The induced vapour pressure between the jaggery and the surrounding medium plays an important role in the removal of moisture from the interior of jaggery product. Compared to openyard drying, this induced vapour pressure will be more in poly house dryer thus hastening the rate of drying. It was observed that drying time for granular jaggery was 11 hours in the poly house to reduce the moisture content of granular jaggery to 1.6% from the initial moisture content of 9.8%. In open yard drying, it took about 16 hours for 3 days to reduce the moisture content of jaggery samples from 9.8 to 1.8%. Hence, there is a saving of 38% time in polyhouse dryer compared to open yard drying. Similar results of 40–55% saving in time were reported by Shahi et al. (2011) during polyhouse drying for selected fruits and vegetables. Asemu et al. (2020) reported saving in time in polyhouse drying of maize grain. Greenhouse drying of jaggery before storage is an effective method to improve the shelf-life of jaggery at lower cost without consuming any other source of energy (Kumar et al., 2018).

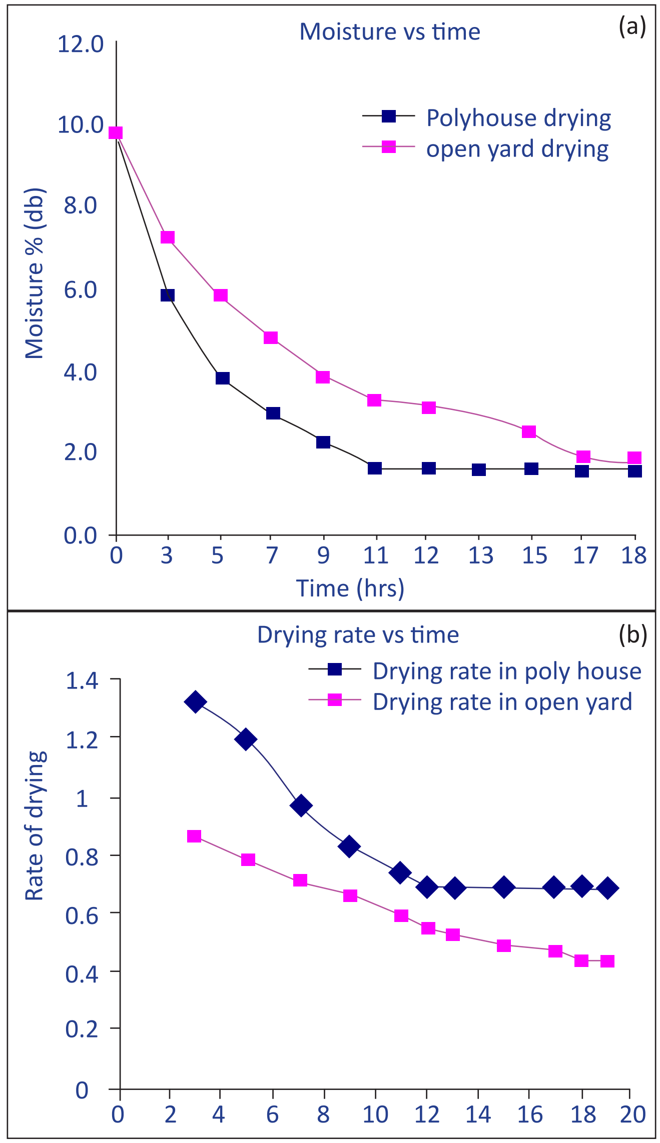

Figure 4: (a) Moisture percent Vs drying time (b) Rate of drying Vs drying time

The drying curve (Figure 4(a)) of granular jaggery followed the general trend of drying curves of other products like cereals, pulses, etc. It was observed that the moisture content of the jaggery samples reduced in an increasing trend at the beginning of the drying process. The reason might be due to the high initial moisture content of the granular jaggery. As the drying process was advanced, the loss of moisture decreased with drying time as granular jaggery reached equilibrium moisture content. The reduction in moisture content under open yard drying was comparatively slower than open yard drying. The drying rate in polyhouse was higher than open yard drying (Figure 4(b)). This may be due to the high temperature generated inside polyhouse compared to ambient air temperature. Also, during polyhouse drying, the removal of moisture from the product was done by conduction, convection and radiation methods of heat transfer. Drying of tomotoes in solar green house dryer took 4 days where as in open sundrtying, it was 5 days. Also the color and quality of tomatoes were reported to be superior compared to conventional drying (Sacilik et al., 2006). Drying of red chillies in solar tunnel dryer was attempted by Joy et al., 2001 and reported two days whereas it took 7-10 days by conventional method. Hence, the high rate of drying in solar poly house dryer resulted in reduction of drying time compared to conventional method. It was reported that the temperature inside the poly house dryer was 62–76% higher than the ambient temperature and the relative humidity inside the dryer varied from 26–50% resulting in high rate of drying (Sangamithra, 2014). In poly house dryer, the solar radiation passes through the transparent sheet and will be retained in the drying chamber thus increasing the temperature of the air. Thus, thermal energy is transferred into the drying chamber and reduces the moisture content of the product. The higher temperature coupled with proper air circulation helped in the high drying rate of granular jaggery inside polyhouse dryer.

3.2. Quality analysis of jaggery

The jaggery dried in polyhouse and the open yard was analyzed for its quality attributes in terms of percentage sucrose and reducing sugars present. Table 2 represents the quality parameters of jaggery. The sucrose percent of jaggery dried in both systems varied insignificantly at 5% confidence levels. However, there was a significant change in color from light brown to dark brown color. In polyhouse dryer, the bright yellow color of jaggery was maintained throughout the drying process. The reason might be the presence of UV stabilized sheet in polyhouse retain the original color of jaggery whereas, in open yard drying, the product was exposed to bright sunlight throughout the drying process making it a little darker as recorded from the L^*, a^* and b^* values of granular jaggery. It was reported by Mustayen et al. (2014) that there will be loss in color of produce in open yard drying due to UV exposure and readsorption of moisture during off sunshine hours cauing unfit for marketability in domestic and international markets. In polyhouse, the solar radiation does not directly falls on the produce avoiding caramelisation and localized heat damage. The solar dryers are reported to be suitable for retaining vitamins in preserved fruits, and colour in highly pigmented commodities (Jain and Tiwari, 2015). The quality and color of polyhouse dried products were proved to be superior than that in natural sun drying (Sangamithra, 2014)

Table 2: Quality parameters of jaggery

Sl. No.	Parameter	Open yard drying	Polyhouse drying
1.	Sucrose %	$81.1±0.6^a$	$81.7±0.5^a$
2.	Reducing sugars %	$13.5±8^a$	$13.2±0.1^a$
3.	Total Non-sugars %	$5.4±0.3^a$	$5.1±0.2^a$
5.	Color readings		
	L*	$46.2±0.5^a$	$51.9±0.3^b$
	a*	$4.4±0.2^a$	$3.5±0.2^b$
	b*	$3.1±0.1^a$	$5.1±0.2^b$

Alphabets in small letters (a and b) in the superscripts denote that the mean values are statistically; Different within the row at $p<0.05$

The traditional method of drying in direct sunlight is a slow process accompanied with contamination with dust, insect infestation and spoilage due to climatic conditions. This can be overcome by use of conventional fuel or electrical operated dryers. However, in rural areas, the electrical supply is often interrupted and also very expensive. Though the open yard method of drying was economical to the farmers, the drying was carried out in unhygienic conditions and the quality of produce will be effected due to contamination by dust, insects, pets, birds and rain. Also, the color of granular jaggery turns darker in open yard drying as it is exposed to direct sunlight for a longer period which is not desirable by consumers and reduces market value. Hence, polyhouse solar dryer was found to be a better option for large scale drying of granular jaggery to retain its color and quality.

4. Conclusion

Polyhouse solar dryer having a length of 12 m, a width of 2.7 m and a height of 2.7 m was found effective for drying 200 kg of granular jaggery with saving of 38% drying time compared to open yard drying. Drying could be done on large scale under hygienic conditions retaining the bright yellow color of the jaggery.

5. Acknowledgment

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