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Research Article

Comparative Study on Oven and Solar Drying of Agricultural Residues and Food Crops

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Abstract. The current study examined reduction of moisture from agricultural energy and food crops in a conventional oven to a solar dryer at various treatment periods at temperature between 40 ± 10 °C. Sugarcane bagasse and Phragmites Australis had initial moisture of 50.8 % and 6.07 % by dry weight, respectively, with higher heating values (HHV) 6548.5 kJ/kg and 17653.02 kJ/kg respectively. The moisture content of bagasse and phragmites were decreased by 51.31% and 68.69% respectively using oven drying, while the moisture content of bagasse and phragmites was reduced by 48.01% and 66.22% respectively, using solar drying with 5 hrs treatment time. Corresponding increase in HHV's observed in bagasse to 11195.6 KJ/kg (oven drying) and 10998.1 KJ/kg (solar drying), while HHV of phragmites increased to 18706.79KJ/kg (oven drying) and 18685.36KJ/kg (solar drying). Green chillies had a moisture content reduction by 33.69 % (oven) and 8.28 % (solar), whereas grapes had a reduction by 31.20 % (oven) and 7.88 % (solar) with 5 hrs treatment time. The oven drying approach revealed higher carbohydrate content in food crops when compared to solar drying, while both treatments showed a similar drop in protein, fat, and vitamin C contents. Statistical and energy analysis observed that comparing solar drying; the oven drying eliminates slightly higher moisture content and have less drying energy requirements. The amount of heat energy required for drying unit mass of bagasse was 0.476 kJ/kg (oven) and 0.556 kJ/kg (solar), for phragmites it was 0.074 kJ/kg (oven) and 0.092 kJ/kg (solar), for chilles 0.524 kJ/kg (oven) and 0.576 kJ/kg (solar) and for grapes 0.123 kJ/kg (oven) and 0.157 MJ/kg (solar). According to the results solar drying required greater quantity of heat energy than oven drying. Mass transfer analysis showed drying constant of bagasse and phragmites were higher initially, then showed reducing trend with respect time. Furthermore, it was observed that the effective diffusivity and mass transfer coefficient were found reducing with respect to increasing drying treatment time. The research findings of renewable solar drying, on the other hand, are comparable to those of oven drying, demonstrating that there is still enough untapped heat energy available for its utilization in biomass thermo-chemical conversion methods.

Keywords: Oven drying, Solar dryer, Bioenergy, Higher heating value, Vitamin C, Carbohydrates

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1. Introduction

The economy of Pakistan (25% GDP) is associated with agricultural sector, which produces massive quantities of agricultural residues and by-products or power generation, the country usually imports fossil fuels and crude petroleum oil to meet its energy demand. A previous study showed that the country has the potential to generate 76% of its total electricity requirement from agricultural energy crops and its residues annually to subsidize and fulfil the requirements of energy demand through environment friendly manner (Saeed *et al.* 2015). The country's developing economy is mainly based on the agricultural sector, but its dire energy crisis is a barrier to its industrial development. About US $7–9 billion are frequently being squandered by Pakistan on fossil fuels imports to meet its demand for transportation and energy sectors. Looking at this significant issue, Alternative Energy Development Board (AEDB) of Pakistan is currently working to examine and promote renewable energy technologies such as solar, wind, hydropower, and biofuels to reduce the series energy shortfalls. Although there are different types of renewable energy resources available worldwide, but biomass is considered as an easily accessible source to produce renewable bioenergy (Saghir *et al.* 2019). Massive number of agricultural and food crops are produced each year; however, the availability of fully sufficient and convenient technology is not accessible for post-harvest and reaps care in Pakistan. Due to this reason, the percentage of generated food crops wastage and residue is about 50% to 60% per annum causing a huge amount of economic loss (Kumar and Kalita 2017).

Solar thermal energy is the most efficient and cost-effective solutions to reduce moisture content for

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converting agricultural residues as bioenergy feedstock and for preservation of food crops. Moisture is evaporated near the surface during a simultaneous transfer of heat and mass by a variety of mechanisms, including liquid and vapour diffusion, capillary and gravity fluxes, and flow produced by shrinkage and pressure gradients. Reduced moisture content, decreases the risk of microbe growth, minimises moisture-mediated deteriorative reactions like enzymatic reactions, non-enzymatic browning, and pigment oxidation. Nowadays, hybrid solar dryers are used in comparison to the old open-air sun drying process resulting in decreased crop losses. Conduction, convection, and radiation modes of heat transmission is used to remove moisture from raw agricultural products during the solar drying process. In the solar drying process, radiation passes through a transparent sheet and is retained as heat in a drying chamber or solar collector at a temperature between 30 to 60 ^{o}C. Thermal energy is then transferred to the drying chamber by natural convection in a passive system; hot air is led into the chamber by fans or blowers in an active system. Natural convection dryers and forced convection dryers are two most common system used in food crop drying. The direct passive solar dryers are based on natural convection includes a drying chamber usually consists of an insulated box with inlet, outlet holes and a transparent glass cover. During drying, the solar radiation is partially reflected to the atmosphere while the rest is transmitted into the cabinet and absorbed by the materials. The average drying efficiency of the passive dryer ranges from 20 to 40%, depending on the type of materials, airflow rate, and location. While active solar dryers have a ventilation system to circulate heated air inside the drying chamber from the solar collector to the drying chamber. Electric fans or blowers, helps in drying can be harnessed from a photovoltaic (PV) module or grid. The passive mode of the greenhouse solar dryer, a ventilator or chimney is built for the natural circulation of heated air. An active dryer has been reported to be more suitable for crops with a higher moisture content. To achieve high drying efficiency and product quality, the optimal temperature and air mass flow rate must be controlled.

Hybrid solar dryer are used for agricultural materials under direct solar radiation or back-up energy or stored heat in the absence of sunlight. The air is pre-heated by another auxiliary source of energy such as a solar PV module, electricity, liquefied petroleum gas, diesel, or biomass (Udomkun et al. 2020). Lignocellulosic biomass materials are attracting increasing attention as renewable, economical and abundant resources to reduce dependency on petroleum resources for the production of bioenergy. However, biomass materials with high moisture contents $\geq$ 50% by dry weight are not a suitable feedstock for conventional thermochemical conversion technologies such as gasification and pyrolysis. Moisture in raw biomass materials is also undesired because fuels derived from biomass having high moisture contents, badly affects the combustion properties (Irmak 2019).

The moisture content in bagasse by-product of sugarcane industry varies considerably with the degree of extraction, but under average value of the moisture content in bagasse reaches 52% by dry weight. The utilization of bagasse during the combustion process in a boiler requires considerable amount of furnace energy in evaporating the water contained in the fresh bagasse; therefore, decreases combustion efficiency. In return it reduces the calorific value, furnace temperature, reduces stability of boilers operation, decreasing the vaporization coefficient and combustion velocity. The results showed reduction in bagasse moisture content by 10-15% by weight, results in enhancement of higher heating values of bagasse to 4628 kCal/kg at 35 % moisture content from 4522 kCal/kg at 50 % moisture content with corresponding improvement in boiler efficiency from 69% to 81% (Salunk *et al.* 2017). Limited ssustainable biomass resources and their utilization needs to be more efficient. For that reason, drying, considerably improves the quality of woody biomass by increasing its calorific value and provides easy seasonal energy storage as extended storage life. A research study showed that solar heat can be successfully applied to thermal drying of biomass through convective solar dryer. Generally, moderate drying temperatures are used (typically 20 to 50°C) which found to be advantageous for ensuring homogenous drying of wood particles and for preventing changes to the physical structure of the biomass and loss of volatiles. Newly harvested logging residues and small diameter fuel wood have a moisture content of over 50 % by dry weight, have low calorific value of fuel. Therefore, fuel wood with moisture content of 50%, the effective calorific value is 16 MJ/kg compared with 19 MJ/kg for dry fuel (Raitila and Tsupari 2020). Similarly, the effect of traditional and improved solar drying methods on the sensory quality and nutritional composition of the dried fruit products showed that different solar drying methods were capable of retaining the sensory quality (i.e., taste, aroma, colour), nutritional values, mineral content composition and improves the shelf life of dried fruits (Mohammed et al. 2020).

A comparative study was conducted on the physicochemical and antioxidant properties of whole hihatsumodoki (Piper retrofractum Vahl) to evaluate the application of solar thermal drying and oven drying operating with conventional energy. Based on natural drying phenomena and changes in metrological conditions the solar drying temperature was between 30 to 50 ^{o}C (from 10 am to 3pm) for 18 hrs, while the oven-drying for 24, 6, and 4 hrs at 50, 70, and 90 ^{o}C, respectively. Desirable dry matter (24% relative mass) and water activity (0.50) values were obtained after solar drying for 18 hrs, and oven drying for 24, 6, and 4 hr at 50, 70, and 90 ^{o}C, respectively (Takahashi et al. 2018). The drying time using solar dryer is generally longer than other drying techniques that use electricity due to the lower and inconsistent temperature within its drying chamber. Research investigation conducted on drying tropical fruits like bananas, papaya and pineapple using an oven at temperatures of 65 to 85^{o}C, and the results were compared with the outcomes of drying using a simple wood solar cabinet dryer between 27 to 34^{o}C. The results showed that the increase in the temperature of drying in the oven from 65 to 75 ^{o}C did not change the drying time significantly, but the drying time was reduced significantly to 70% when the temperature was increased to 85 ^{o}C. The fluctuation of temperature and air flow within the solar dryer was between 27 to 34 ^{o}C and 0.12-1.52 m/s, respectively, slowed down the drying process, resulted ~~to~~ prolong ~~of~~ drying time requirement. The drying time to reduce the moisture content from 80 to 60% for the solar drying was between 31 to 74 hrs while for oven drying with temperatures of 65 to 85 ^{o}C was between 1 to 5 hrs (Baini et al. 2018). In a study conducted by Izaora Mwamba et al., two drying methods (solar and oven) were used to dry a variety of mango. The temperature of drying in the oven was fixed at 50°C, whereas in the solar dryer it was varied from 22.4°C to 40.7°C. The drying yield of 33% for sun dried mango versus 26% for oven dried mango was achieved; Mango, dried in the sun has a high concentration of vitamin B6, vitamin C and mineral elements (Ca, Mg and Fe) along with the presence of vitamins (A, D and E) after the drying operations. The solar drying of the mangoes is possible and gives acceptable results compared to the results of dried mango in an oven where the temperature is controlled. From the physicochemical and biochemical point of view, solar drying of the mango boosts a number of nutrients that we encounter in fresh mango, including vitamins, minerals, proteins, etc. In the microbiological aspect, oven-dried mango is more stable after 90 days storage at room temperature and free from contamination, while sun-dried mango shows contamination of fungal germs after 90 days of storage. The latter is due to transport and storage conditions. Thus, solar drying technology is transferable to farmers to reduce post-harvest losses and boost their savings (Izaora Mwamba, Karl Tshimenga et al. 2017).

The current research compares the influence of oven and solar drying on physical, chemical, and biochemical (nutritional) characteristics of agricultural residues and food crops respectively, before and after drying for various treatment times. The comparison of both oven and solar drying treatments includes thermal energy requirements, impact of drying on reaction kinetics, mass transfer properties and statistical analysis. This research work is beneficial for enhancing the energy content of agricultural residues to enable the production of bioenergy and the long-term storage of food crops without spoiling.

2. Materials and Methods

All the experimental work of drying and characterization of agricultural energy and fruit crops were conducted at the Department of Environmental Engineering, NED University, Karachi at room temperature 28 ± 1 °C. Experimental results were obtained twice to get an average value for further calculations.

2.1. Agricultural energy and fruit crops used in this study

Sugarcane Bagasse (*Gramineae Saccharum Officinarum L.*) and Common reed (*Phragmites Australis*) were collected from sugarcane industry and open land farms near Karachi, while Green chilies (*Capsicum Annum L.*) and Grapes (*Vitis Vinifera L.*) as food crops were procured from local market and were sealed in plastic zipper bags to avoid any moisture loss. Bagasse (*Gramineae Saccharum Officinarum L.*) and Phragmites Australis were cleaned with cotton cloth and cut into 10 mm size pieces by using scissors and stored in an airtight plastic bag for experimental work,while the Green Chillies and Grapes were washed, cleaned thoroughly with tap water to avoid any kind of contamination and dust particles, then the fruit crops were dried with a cotton cloth and each sample was weighted with an electronic analytical balance (AB304-, Mettler Todelo, Switzerland). However, green chillies and grapes were cut into small size pieces (5mm long) after seed removal for drying operation.

2.2. Drying of Agricultural energy crops and food crops

For drying comparison two types of equipment were used in this research study i.e., locally fabricated forced convection cabinet solar dryer attached with a solar collector and conventional hot air oven (YCON01, Taiwan) with volume 0.133 m^3. Solar cabinet dryer consists of two components i.e., solar collector (141 cmx 66.7cm x 4.7 cm= 0.047 m^3) with top glass cover 3 mm in thickness and cabinet drying chamber (50 cm x 50cm x 42 cm= 0.105 m^3). Cabinet drying chamber was made up of plywood outer surface with inner lining of aluminum absorber plates and glass wool layer (5 mm) provided for insulting to avoid heat losses through wall conduction. A case fan (120 mm, 2.3 W, China) was attached with cabinet drying chamber having 1200 rpm speed and a flow rate of 0.045m^3/sec for forced convection. Two (k-type) temperature measuring thermocouple (Max 6675) connected with Arduino (UNO DS18B20) were installed in the drying chamber at the midpoint and exit port. Solar collector and drying chamber were connected with a steel pipe (10 mm), insulated with glass wool (see the schematic diagram of solar collector attached with solar drying chamber, Figure 1). Samples were placed on the mesh trays in the solar drying cabinet. In the oven, temperature was remained constant at 50 ± 1 °C, while the solar dryer chamber temperature varied between 30 to 50 °C. The sun drying experiment was carried out from 10:00 a.m. to 15:00 p.m. during the month of November. Solar radiation intensity (W/m^2) falling on the solar collector was measured by (ST1307 Standard Instruments, China), while ambient temperature and relative humidity was measured by (MTAM-0114, Fluke Corporation, USA).

Each 5g of Bagasse and Phragmites Australis was weighed and placed in a china dish over in the oven and solar cabinet dryer's bar trays for 1 to 5 hours of drying time intervals. While, 10 g of Green Chillies and Grapes samples, on the other hand, were dried in a standard oven and with solar dryer. Arduino sensors were used for the collector and solar drying chamber temperature measurements. Air flow velocity through solar cabinet dryer was measured by Kestrel Velocity meter (Pocket Weather Tracker, 4000NV, USA).

2.3. Physicochemical analysis of agricultural crops

The following physical and chemical properties of agricultural crops were measured by following the protocol and mathematical expressions from the previous literature (Ahmed *et al*. 2021).

2.3.1. Moisture Content Determination

The moisture content of the biomass was determined using the oven drying method, which used heated air to calculate the amount of moisture released by the biomass. Each agricultural crop sample (1 g) was kept in an oven for 3 ~~2~~ hrs at 105 °C. The sample was then placed in a desiccator and allowed to cool to room temperature. Then the moisture content was calculated using the Eq 1.

$$\text{Moisture Content (\%)} = \frac{W_1 - W_2}{W_3} \text{ X } 100\% \qquad (1)$$

Where W_1 is the weight of crucible and sample before drying (g), W_2 weight of crucible and sample after drying (g) and W_3 is the initial weight of the sample (g).

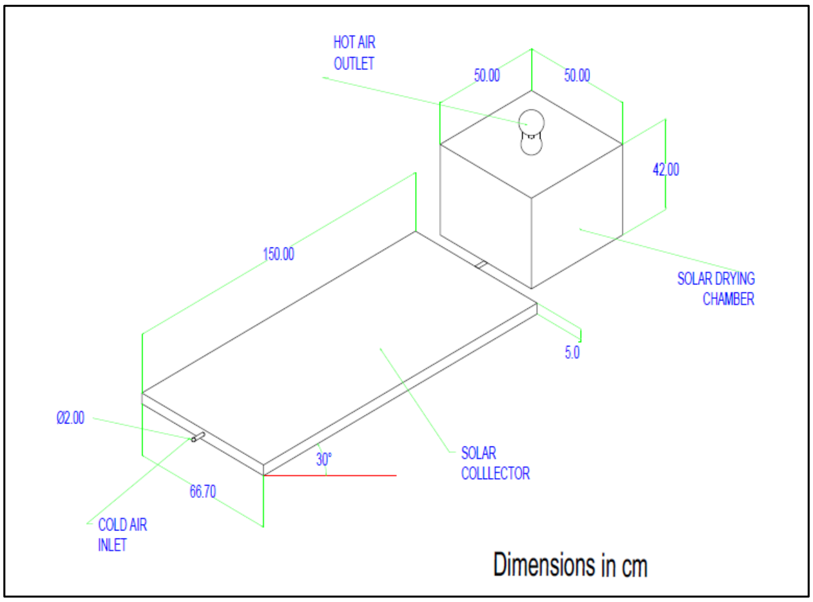

Fig 1. Schematic diagram of the cabinet dryer with a flat plate solar collector

2.3.2 Volatile Matter Content

The volatile matter content was determined by combusting 1 g of biomass sample in a muffle furnace for 15 min at 550°C with covered sample in a crucible (Thermolyne, Model F47925 Programmable Benchtop Type 47900). Then sample was transferred to a desiccator to allow the temperature of sample to drop down to room temperature. Then the amount of volatile content in the sample was measured by two steps i.e., weight loss and then volatile matter evaporated during drying process using equations 2.

$$\text{Weight loss (\%)} = \frac{W_4 - W_5}{W_3} \quad (2)$$

$$\text{Volatile Matter Content (\%)} = \text{Weight loss (\%)} - \text{Moisture Content (\%)} \quad (3)$$

In Equation (2), W_4 is the weight of sample plus crucible before heating (g) and W_5 is the weight of sample plus crucible after heating (g).
Volatile matter content (%) is the difference between weight loss (%) calculated in Equation (2) and moisture content (%) value calculated in Equation (1).

2.3.3. Ash content

Ash content in the biomass sample was measured by combusting, 1 g of biomass sample in a muffle furnace without covering the crucible for 15 min at 550 °C and then it was transferred into a desiccator for cooling. The weight of sample was measured, and total ash content was calculated by Eq 4;

$$\text{Ash content (\%)} = 100 - \frac{W_6 - W_7}{W_3} \times 100 \quad (4)$$

W_6 is the weight of sample plus crucible before combustion (g) and W_7 is the weight of sample plus crucible after combustion (g).

2.3.4. Fixed Carbon Content

Fixed carbon content (%) in the biomass samples were calculated by subtracting the moisture, volatile matter and ash contents from 100 by using equation 5.

$$\text{Fixed Carbon Content (\%)} = 100 - \big(\text{Moisture content (\%)} + \text{Volatile Matter (\%)} + \text{Ash Content(\%)}\big) \quad (5)$$

2.4. Higher heating value

Higher heating values of agricultural energy crops were determined by proximate analysis using empirical equation 6 (Jigisha et al. 2005);

$$\text{HHV} = 0.3536\ \text{Fixed Carbon Content} + 0.1559\ \text{Volatile Matter Content} - 0.0078\text{Ash Content (MJkg)} \quad (6)$$

2.5. Physicochemical and biochemical analysis of food crops

The following physical and biochemical properties of food crops were measured.

2.5.1. Moisture Content

It was determined as mentioned earlier in section (a) for agricultural residues.

2.5.2. Total Ash Content:

Total ash content was determined by following the protocol as explained earlier in section (b) for agricultural residues.

2.5.3. Protein Content

The protein content in food crops was measured by Standard Biuret Reagent Process with 0.2N Sodium Hydroxide Solution, Biuret Reagent and Green chillies/ Grapes Extract using Spectrophotometer (DR 5000, HACH, USA) at 590nm for each sample and then plotting against the standard protein curve. Biuret Reagent (9 mL) was mixed well with 3mL of green chilies/grapes extracts, once slight change in colour was visible, its concentration was measured by spectrophotometer to quantify the available protein in the samples following the protocol mentioned in the literature (Liu and Pan 2017).

2.5.4. Fats/Lipids Content

Lipid content present in green chilies and grapes were measured by organic solvent extraction method as mentioned in the literature (Srigley and Mossoba 2016). Each 5g of dried and crushed sample was mixed with 10mL of analytical grade acetone. Then the liquid mixture was transferred into a petri dish and kept for 24 hrs for drying at room temperature. Afterwards the mixture was filtered, and weight of the extracted fats/lipids were measured after drying solvent in an oven. The equation 7 was used for the determination of fats/ lipid content:

$$\text{Lipid yield } (\%) = \frac{\text{Weight Lost from Food}}{\text{Weight of Raw Food}} \text{ X } 100 \tag{7}$$

2.5.5. Vitamin C Content (Ascorbic Acid)

Ascorbic acid concentration was determined by the Titrimetric Method (NaOH Acid-Base Titration), where 0.05M sodium hydroxide acts as a base which reacts with the available quantity of ascorbic acid present in food crops. Fifty (50) ml of NaOH was filled up in a burette, while 10mL of extracted solution had 2 to 4 drops of phenolphthalein added as the indicator of the final acid-base reaction in the form of a light pink colour. Overall, three measurement were conducted for each extracted sample to get accuracy in results (Almajidi and Algubury 2016).

2.5.6. Carbohydrates Content

Carbohydrate content in food crops were obtained using the following equation as mentioned in previous literature (Sarkiyayi and Agar 2010);

$$\text{Carbohydrates}(\%) = 100 - (\text{Moisture Content}(\%) + \text{Protien Content}(\%) + \text{Fat Content}(\%) + \text{Ash Content}(\%) \tag{8}$$

2.6. Heat energy requirement for drying agricultural energy crops and food crops

The amount of heat energy required was calculated to reduce moisture content in agricultural crops and food crops with respect to treatment time. The amount of heat energy required for drying is a function of temperature and moisture content. Therefore, latent heat of vaporization (h_{fg}) was calculated by using the expression written below (Hossain 2015).

$$h_{fg} = 4186\,[597 - 0.56(T_P)] \tag{9}$$

Where T_p is the product temperature during thermal treatment (°C)

Quantitatively, the amount of heat energy (E) required was calculated by multiplying the moisture removed %, latent heat of vaporization and volume fraction as a scale up factor (i.e. volume of sample in a container 100mL/ total volume of equipment drying chamber 105000mL) using the following mathematical expression (Ali and Watson 2014, Hossain 2015);

$$E = M_r \text{ x } h_{fg} \text{ x Volume fraction} \tag{10}$$

Where M_r is the moisture removal %

The equation 11 was used to compute the collector usable heat energy gain required to dry a particular mass of agricultural and food crops (Hossain 2015);

$$Q = \left[Cp \text{ x } Mp\,(T_c - T_a) + h_{fg} M_{wf}\right] \tag{11}$$

Where Q is the useful heat energy gain (kJ); C_p is the specific heat capacity; M_p initial mass of sample (kg); M_{wf} mass of sample after drying treatment (kg); T_a is the ambient temperature (°C) and T_c is the temperature of solar collector (°C).

2.7. Drying kinetics and mass transfer analysis

Thin-layer model was followed to study the drying kinetics and mass transfer properties of biomass as per literature (Guiné and Lima 2020), that correlates the change in moisture content during drying phase with parameters such as the drying constant, k (1/s), or the lag factor, k_0 (dimensionless), which account for the combined effects of numerous transport phenomena taking place during drying process. Thin-layer model relates moisture ratio (MR) to time (t) according to the following equation expressed in the logarithmic form, corresponding to a linear function.

$$\ln(MR) = \ln k_0 - kt \tag{12}$$

$$MR = \frac{(W - W_e)}{(W_0 - W_{e)}} \tag{13}$$

Where; W_o, W_e and W are the moisture contents at the beginning, at equilibrium and at any time t, respectively. Correlations for mass transfer includes Biot number for mass transfer, while (Bim), is a dimensionless number that correlates the convective mass transfer coefficient, h_m (m/s), with the diffusivity coefficient, D_e (m/s²);

$$Bi_m = \frac{h_m Z}{D_e} \tag{14}$$

Where z is the characteristic dimension of the system (m).

Dincer and Hussain, proposed an equation to associate the Biot number with Dincer Number (Di) as;

$$Bi_m = \frac{24.848}{D_i^{0.375}} \tag{15}$$

Now, the Dincer Number is defined as;

$$D_i = \frac{u}{kz} \tag{16}$$

In the above equation, *u* is the flow velocity of drying air (m/s), k is the drying constant and z is the characteristic dimension. Furthermore, Dincer and Dost proposed an equation to corelate the effective diffusivity, (*De*) to the thin layer drying constant (k) by the following mathematical expression;

$$D_e = \frac{KZ^2}{\mu_1{}^2} \tag{17}$$

Where μ_1 is a function of the Biot number and is given by;

$$\mu_1 = \text{Tan}^{-1}(0.64\,Bi_m + 0.38) \tag{18}$$

2.8. Statistical Analysis

In order to compare the results of moisture removal (%) from agricultural energy crops and food crops by both heat treatment methods, statistical procedure of two tailed t-test method (Microsoft Excel 2010, USA) was used at a significance level of 0.05.

3. Results and Discussion

The metrological conditions, such as ambient temperature and relative humidity, were measured for the month of November 2019. For the solar drying of agricultural and food crops, parameters such as solar irradiation, midpoint and outlet temperatures in the cabinet solar dryer before and after each treatment time were measured and presented in Table 1. Furthermore, agricultural residues and food crop samples before and after 5 hrs solar drying treatment are shown in Figure 2.

3.1. Effect of drying treatment on physico-chemical properties of agricultural energy crops:

Table 2 depicts the variation of moisture content (%) from 1 to 5 hrs, by conventional oven drying and solar drying methods on sugarcane bagasse and phragmites. It was observed that increasing drying time had an influence on the moisture content reduction from bagasse. The results showed that moisture content was reduced to 24.73% with oven drying and 26.41% with solar drying in 5 hrs as compared to the initial moisture content of raw bagasse of 50.8%. The moisture removal rate was found to be 0.515 g/hr by oven drying, while it was 4.5 g/hr by solar drying for bagasse for 5 hrs of treatment, as depicted in Figure 3, with increase in corresponding HHV.

By using a solar dryer and an oven for variable treatment durations, a change in the proximate analysis of bagasse was found in terms of volatile content, ash content, and fixed carbon. After 5 hrs of oven drying, the volatile content reduced from 81.2 % to 66.47 %, while the ash level increased from 2.90 % to 9.57 %. After 5 hrs of drying, the amount of fixed carbon was increased to 23.96 % from 15.90% using the oven method. In addition, the results of solar drying exhibited similar patterns. Solar cabinet drying reduced the volatile content of raw bagasse from 81.2 % to 69.20%, increased ash content from 2.9 % to 8.09 %, and increased fixed carbon from 15.90 % to 22.72 %.

Drying procedures resulted in enhancement in higher heating values (HHV) and moisture content reduction in dried bagasse samples as reported by literature (Salunke *et al.* 2017). The moisture content reduced to 24.73% from 50.80%, and raised the HHV of bagasse samples to 11195.60kJ/kg from 6548.50kJ/kg. Similarly, the moisture content of bagasse decreased to 26.41% from 50.80% by solar drying and resulted in a corresponding increase in HHV value to 10988.10kJ/kg from 6548.50 kJ/kg. It is worth mentioning that with 1 hr drying time the HHV was increased to 1992.7 kJ/kg using oven drying, while it was higher with solar drying for the same treatment time to 2282.70kJ/kg. But after 2 hrs of treatment with oven drying, HHV increased more efficiently and incessantly (2915.8 kJ/kg) than solar drying (2885.70 kJ/kg), which implies that more moisture content was removed by the oven drying method. Nevertheless, looking at 5hrs drying time, oven dried bagasse's HHV was marginally higher (4647.10 kJ/kg) which does not indicate a prominent difference in contrast to solar drying of bagasse with HHV value of 4439.60 kJ/kg with the same drying time.

Now, the change in moisture content of Phragmites australis with respect to different drying times and treatment methods are presented in Table 2. Comprehensively, the moisture content withdrawal by oven and solar dryer was found to be compatible and showed similar decreasing trends with respect to increasing treatment time. Raw phragmites had 6.07%, moisture content, while after 5 hrs of oven drying it was reduced to 1.9%, with 0.689 g/hr more moisture removal rate than raw phragmites; conversely the maximum moisture content after drying by solar drying was 2.05%, with moisture removal rate up to 4.686 g/hr with increasing HHV corresponding values (see Figure 3).

Phragmites biomass proximate analysis after thermal treatment revealed changes in volatile content, ash content and fixed carbon content. Overall, it was observed that increment in the fixed carbon and ash content caused reduction in volatile content with respect to different treatment times. The decreased variations in volatile content were found after 5 hrs of drying from 71.17% to 62.91% which was more or less similar by solar drying from 71.18% to 62.36%. On the contrary, by oven drying the ash content inclination was observed till 14.10% from 11.54% with increase in fixed carbon to 21.21% from 11.21% for 5 hrs of drying treatment. Furthermore, by using solar dryer method, the ash content increased from 11.51% to 14.57% and fixed carbon increased from 11.21% to 21.60%.

Oven and solar drying of phragmites exhibited decrease in moisture content and increase in HHV. Overall, it was noted that moisture content reduced in phragmites augmented the HHV by using both methods. Reduction in moisture content to 1.9% from 6.07% in phragmites by oven drying increased the HHV of phragmites to 18706.79 KJ/kg from 17653.02 KJ/kg with a difference of 1053.77 KJ/kg. However, by solar dryer, the moisture content removed was 2.05% along the 18683.02 KJ/kg increase in HHV of phragmites with difference of 1029.99 KJ/kg. Increasing treatment time resulted in more moisture removal and simultaneously enhancing HHV with both drying methods. Nonetheless, by oven drying, higher HHV was observed after 2 hrs treatment as compared to solar drying method. Both methods of drying showed slightly consistent, undistinguished, and stable HHV subsequently after 4hrs treatment. The overall HHV by oven drying was 18706.79 KJ/kg and by solar dryer method it was enhanced to 18685.36 KJ/kg.

It was observed in the previous study that that moderate drying temperatures used (typically 20 to 50 °C) are advantageous for ensuring homogenous drying of biomass for preventing higher loss of volatile content (Raitila and Tsupari 2020). This is what may occur when the energy crop samples are dried using both drying methods at moderate temperatures that volatile matter was evaporated resulting in higher fixed carbon content, thus enhancing the HHV of the agricultural residue samples. Basically, the fixed carbon of any material gives a rough estimate of the heating value of a fuel and acts as the main heat generator during the combustion. Therefore, release of volatile matter during thermal drying, increases fixed carbon and thus a higher degree of carbonization. Moisture has a substantial impact on the reduced calorific value of all combustion fuels and fuels with a high moisture content produce more exhaust gases during combustion, which lowers the combustion temperature (Mierzwa-Hersztek *et al.* 2019).

Table 1
Meteorological parameters and solar drying chamber temperatures

Treatment Time (hrs)	Solar radiation (W/m^2)	Relative Humidity (%)	Ambient Inlet Temperature (°C)*	Midpoint Temperature (°C)*	Outlet Temperature(°C) *
(10.00 A.M) 0hr	650	49	24 ± 0.28	30± 1.26	27± 1.20
(11.00 A.M) 1hr	680	44	27± 0.86	46± 0.78	49± 0.88
(12:00 P.M) 2hr	950	51	29± 0.55	49± 0.43	51± 0.34
(01:00 P.M) 3hr	1050	52	30± 0.45	50± 0.37	52± 0.65
(02:00 P.M) 4hr	1175	49	31± 0.75	47± 1.52	49± 0.58
(03:00 P.M) 5hr	1008	45	31 ± 0.88	44± 0.74	45± 0.86

**Temperature readings were measured three times and results are presented as mean ± standard deviation (n=3)*

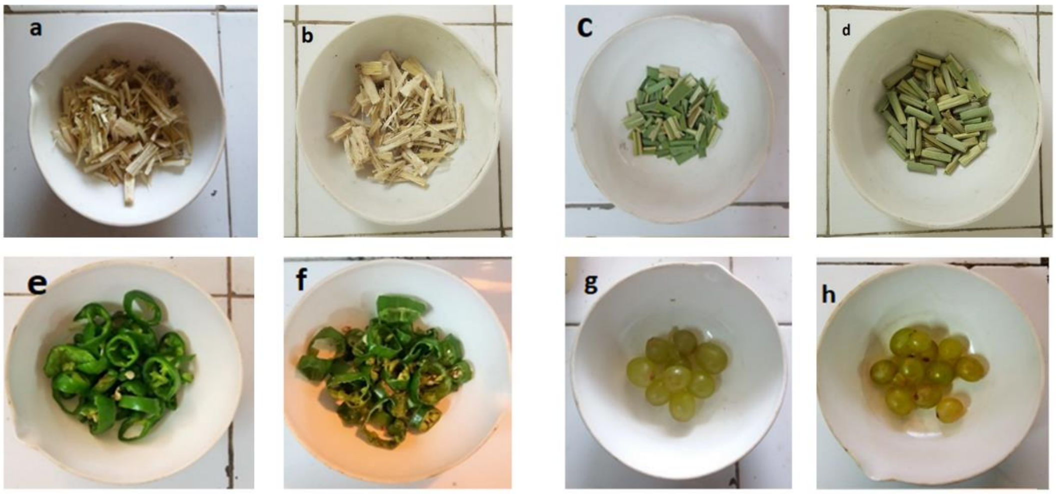

Fig 2. Agricultural residues and food crops before and after 5 hrs solar drying treatment, (a) Raw Bagasse, (b) Bagasse after treatment, (c) Raw Phagmites, (d) Phagmites after treatment, (e) Raw green chillies, (f) Green chillies after treatment, (g) Raw grapes, (h) Grapes after treatment

3.2. Effect of drying treatment on physico-chemical and nutritional properties of food crops

The moisture content removal was found to be higher with oven drying than solar drying method with consistent results (see Table 3). Basically, the removal of moisture content increases the shelf life of food crops for longer period and its consumption during off seasons. The variations in the solar thermal drying were due to fluctuations in the drying chamber temperature from 45°C to 50°C due to change in ambient temperature from 30°C to 35°C during the 5 hrs duration of drying time, while the temperature of the oven was kept constant at 45°C. The moisture content removal from green chilies was observed to be slightly higher with oven drying from 86.92% to 57.63% than solar drying to 59.80% after 5hrs treatment.

The indirect hot air was obtained when solar irradiance fell on the surface of the collector and heated it up, moving hot air towards the drying chamber due to convection and increasing the temperature of the drying chamber. The hot air was then utilized for the drying of the green chilies and grapes samples. The drying of the crops was done by convection heat transfer where the moisture present in the crops was removed when dry air released the moisture in droplets form and exited the solar cabinet from the upper outlet.

Table 3 showed the marginal declining trend in protein concentration using oven and solar dried green chillies and grapes. Oven dried green chillies showed slight change in the protein after 2 hrs of treatment. It was measured that protein content in green chillies dropped from 3.99% to 3.90% by oven drying and from 3.97% to 3.90% by solar drying treatment which showed only a minor difference of 0.02% by oven than solar drying. Similar results were reported with decreasing protein content down to 2.8% from 4.92% occurring due to thermal effect on the vegetable and fruit crops. The temperature was consistent and higher for denaturation of proteins and started to reduce further with increasing treatment time (Carl Ivar Branden and Tooze 1998). Oven and Solar drying of grapes also showed identical results with decrease in protein concentration with respect to increasing duration of treatment.

Reduction in fat content showed more or less similar pattern from both samples (i.e., green chillies and grapes) and treatment methods. The maximum decrease in fats from green chillies was observed in the oven which dropped to 1.14% from 1.43%; whereas solar dried green chillies fat content decreased to 1.20% (see Table 3). The reason for the decline in fat content was due to degradation process of polysaccharides caused by heat treatment applied to food crops (Reis *et al.* 2013). The grapes showed decrease in fat content to 1.49% from fresh grapes fats content of 1.69% by oven drying, while it reduced to 1.51% by Solar drying. Approximately similar results were reported in previous literature showing fat content dropped from 1.77% to 0.92% for the conversion of grapes into raisins (Lokhande and Sahoo 2016).

Table 2
Physico-chemical properties of agricultural energy crops before and after oven and solar drying methods

Treatment Time (hrs)	Oven drying (Bagasse)				Solar drying (Bagasse)			
	Moisture after drying, %	Volatile Content, %	Ash Content, %	Fixed Carbon	Moisture after drying, %	Volatile Content, %	Ash Content, %	Fixed Carbon
Raw	50.8	81.2	2.9	15.9	50.8	81.2	2.9	15.9
(11.00 A.M) 1	39.02	77.98	3.37	18.74	36.08	77.84	3.55	18.91
(12.00 P.M) 2	34.84	75.14	4.95	20.08	31.75	73.67	5.52	20.93
(01:00 P.M) 3	26.67	69.68	8.01	22.66	28.72	79.58	7.4	22.13
(02:00 P.M) 4	25.07	67.86	8.91	23.41	26.89	69.7	7.97	22.62
(03:00 P.M) 5	24.73	66.47	9.57	23.96	26.41	69.21	8.09	22.72
	Oven drying (Phragmites)				Solar drying (Phragmites)			
Raw	6.07	71.18	11.54	11.21	6.07	71.18	11.54	11.21
(11:00 A.M) 1	5.23	69.02	11.8	13.97	5.19	68.33	11.93	14.94
(12:00 P.M) 2	3.77	67.84	12.17	16.24	3.79	66.95	12.4	16.92
(01:00 P.M) 3	3.49	67.24	12.57	16.7	3.63	66.34	12.88	17.16
(02:00 P.M) 4	2.18	64.23	13.29	20.3	2.19	63.47	13.69	20.94
(03:00 P.M) 5	1.9	62.91	14.1	21.21	2.05	62.36	14.57	21.6

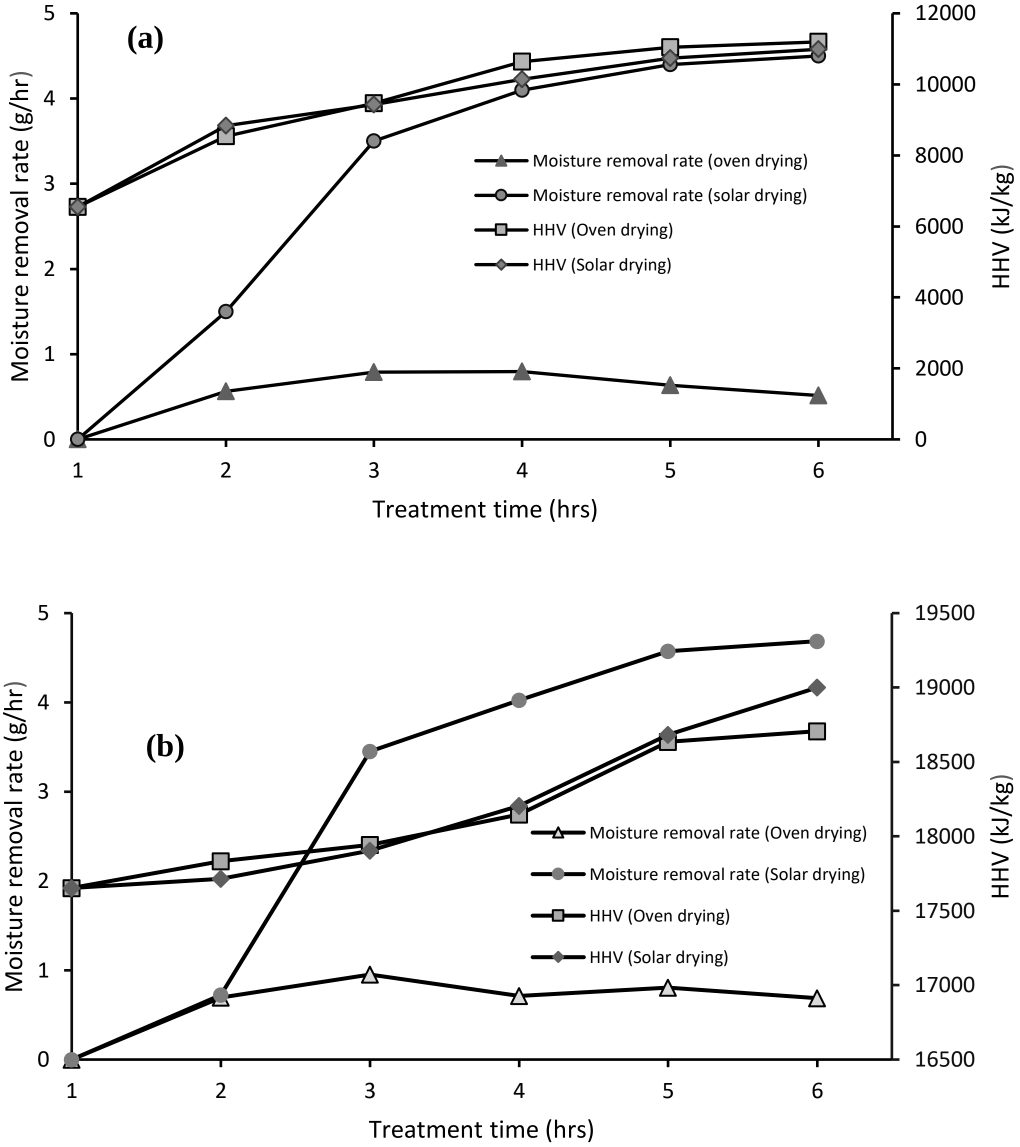

Fig 3. (a) Graphical representation of bagasse moisture removal rate vs HHV at varying drying time, while (b) represents the moisture removal from phragmites vs HHV at varying treatment time

Table 3
Physical and nutritional properties of green chilles and grapes before and after oven and solar drying

Treatment Time (hrs)	Moisture Removal Rate (g/hr)	Moisture after drying, %	Carbohydrate, %	Protein, %	Fats, %	Vitamin C, mg/10gm	Moisture Removal Rate (g/hr)	Moisture after drying, %	Carbohydrate, %	Protein, %	Fats, %	Vitamin C, mg/10gm
	Oven drying (Green Chilles)						Solar drying (Green Chilles)					
Raw	0	86.92	6.83	3.99	1.43	12.51	0	86.92	6.54	3.97	1.43	12.05
(11:00 A.M) 1	0.904	79.15	8.31	3.99	1.43	11.8	0.464	82.9	7.93	3.97	1.43	11.54
(12:00 P.M) 2	0.713	74.57	9.92	3.98	1.41	11.05	5.560	77.50	10.31	3.95	1.39	10.90
(01:00 P.M) 3	0.739	67.75	15.59	3.94	1.35	10.25	7.345	69.98	13.35	3.93	1.31	11.11
(02:00 P.M) 4	0.681	63.35	18.54	3.91	1.25	9.73	8.168	64.91	17.05	3.91	1.23	9.92
(03:00 P.M) 5	0.676	57.63	22.53	3.90	1.14	9.57	8.679	59.80	20.64	3.90	1.20	9.73
	Oven drying (Grapes)						Solar drying (Grapes)					
Raw	0	82.85	13.68	1.23	1.69	0.519	0	82.85	13.36	1.26	1.69	0.514
(11:00 A.M) 1	0.264	81.35	14.41	1.23	1.69	0.516	0.166	81.48	14.99	1.26	1.69	0.509
(12:00 P.M) 2	5.240	80.67	14.51	1.2	1.67	0.510	5.178	80.11	15.28	1.24	1.67	0.503
(01:00 P.M) 3	6.851	78.98	15.69	1.18	1.63	0.502	6.830	79.3	15.82	1.21	1.61	0.497
(02:00 P.M) 4	7.698	77.50	16.39	1.17	1.57	0.496	7.690	77.18	16.47	1.20	1.59	0.495
(03:00 P.M) 5	8.188	75.99	17.29	1.15	1.49	0.49	8.201	76	17.25	1.18	1.51	0.492

The variations in the carbohydrate content of green chillies and grapes showed increment in their increase due to increasing thermal treatment exposure and duration of drying treatment by both drying mechanisms. Table 3 presenting the percentage of carbohydrate in chillies increased from 6.83% to 22.54% by oven drying and from 6.54% to 20.64% by solar drying, while consistent change in the carbohydrate content was observed in grapes due to drying treatment. The increase was from 13.68% to 17.29% by oven drying and 13.36% to 17.25% by solar drying methods. This change in carbohydrate concentration was due to Maillard reaction and the changes in the amount of glucose and fructose in the food crops as reported by previous literature (Hoseney 1984).

The vitamin C concentrations in green chilies and grapes before and after drying treatment are presented in Table 3. Ascorbic acid is highly sensitive with heat treatment and duration of treatment (Mohammed 2013). The vitamin C concentration of green chillies dried in oven was 9.57mg/10g sample, whereas solar dried green chillies had vitamin C concentration of 9.73mg/10g sample, showing presence of 0.62mg/10g of vitamin C retained by solar drying method as compared with oven drying method. Similar result of decreasing concentration of ascorbic acid was observed by Grewal (Grewal et al. 2017). On the other hand, the grapes' vitamin C concentration results also showed decrease in its concentration to 0.490mg/10g with oven drying, while solar dried grapes' concentration declined to 0.491mg/10g. The reduction in ascorbic acid concentration was also reported in previous literature (Elnamer et al. 2018), that due to heat treatment of grapes resulted in reduction from 0.464mg/10g in seedless grapes.

3.3. Analysis of heat energy requirement for oven and solar drying treatments

Looking at the comparison of energy requirement for agricultural energy crops and food crops using oven and solar drying treatments (see Table 4), it was observed that energy required to reduce water content from biomass was lower in oven drying as compared to solar drying method for both 1 and 5 hrs of treatment. At treatment time of 5 hrs, solar drying had higher energy demands of 0.556 kJ/kg (bagasse), 0.092 kJ/kg (phragmites), 0.576 kJ/kg (green chilies) and 0.157kJ/kg (grapes) as compared to oven drying treatment per kg of agricultural energy crops and food crops. This was basically due to the thermal losses from the solar drying chamber, but it is worthwhile to mention that solar drying results are comparable to oven drying treatment. Solar drying is environmentally friendly in contrast to oven drying which consumes conventional fossil fuel-based energy. Moreover, heat energy required for reducing water content from bagasse and green chillies were observed to be higher than those for phragmites, straws and grapes. Because bagasse and green chilles had more moisture content than phragmites and grapes, therefore they required more thermal energy for the removal of moisture content.

Collector useful heat energy gain (Q) versus heat energy required to dry the samples (E) was compared in Figure 4. It was observed that heat energy demands for drying samples were less in all the four samples of agricultural energy crops and food crops against useful heat gain by the solar collector as the heat energy requirement for drying samples was calculated based on the volume fraction ratios' more realistic factor for scaling up drying treatment.

It is also expected that a solar drying chamber exposed to sunshine will absorb more heat energy and it will help to enhance heat energy available for other useful applications (Hossain 2015).

Table 4
Energy requirement for drying agricultural energy crops and food crops

Treatment Time (hr)	Temperature (°C)*	Latent heat of vaporization (KJ/kg)	Moisture Removed %	Volume Fraction	E (kJ/kg)	Temperature (°C)*	Latent heat of vaporization (KJ/kg)	Moisture Removed %	Volume Fraction	E (kJ/kg)
Oven Drying (Bagasse)						Solar Drying (Bagasse)				
1	50 ± 5	2381.834	11.77	7.5187×10^{-4}	0.211	46 ± 1.44	2391.211	14.71	9.5238×10^{-4}	0.335
5			26.06		0.467	44 ± 1.50	2395.899	24.38		0.556
Oven Drying (Phragmites)						Solar Drying (Phragmites)				
1	50 ± 5	2381.834	0.83	7.5187×10^{-4}	0.015	45± 1.38	2393.555	0.87	9.5238×10^{-4}	0.020
5			4.16		0.074	44± 1.55	2395.899	4.01		0.092
Oven Drying (Green chilles)						Solar Drying (Green chilles)				
1	50± 5	2381.834	7.76	7.5187×10^{-4}	0.139	35± 1.34	2416.996	6.66	9.5238×10^{-4}	0.153
5			29.28		0.524	39± 1.38	2407.62	25.11		0.576
Oven Drying (Grapes)						Solar Drying (Grapes)				
1	50± 5	2381.834	1.49	7.5187×10^{-4}	0.027	35± 1.43	2416.996	1.36	9.5238×10^{-4}	0.003
5			6.85		0.123	39± 2.17	2407.62	6.84		0.157

**Temperature readings were measured three times and results are presented as mean ± standard deviation (n=3)*

3.4. Calculated effective diffusivity and convective mass transfer analysis

The calculated drying kinematics parameters of biomass using a solar dryer based on a thin layer model are presented in Table 5. The fan drying velocity of air was measured as 3.45 m/s and the characteristic dimension (z) was calculated by the ratio of volume of drying container (3×10^{-4} m^3) divided by the surface area of the drying container (0.0452 m^2), which comes to 0.00662. The equilibrium moisture content of bagasse, phragmites, green chilies and grapes are 10%, 1.5%, 17.88% and 30 % respectively. The results of drying constant (k) of bagasse and phragmites were found to be higher initially and then showed a declining trend with respect to time. This is because the solar dryer air reached approximately 46 °C in 1 hr from its initial ambient air temperature (24 °C) entering into the drying chamber, promoting higher removal of moisture content. Furthermore, it was observed that the effective diffusivity (D_e) and mass transfer coefficient (h_m) were found to be reducing with respect to increasing drying treatment time. Though the increasing drying treatment time increases drying temperature with increasing rate of diffusion and mass transfer coefficient of fermented cocoa beans mentioned in literature (Koua, Koffi et al. 2019). However, in the current investigation, it showed that there was no fermentation process involved before drying which results in more moisture content and surface porosity. Therefore, the trend of diffusivity (De) and mass transfer (hm) coefficients were decreasing with respect to increasing drying time. It was also noted that the drying produces shrinkage in particle size and increased porosity due to reduction in moisture content using both drying treatments.

Another factor which governs the heat transfer through biomass are surface convection and internal conduction i.e., Biot Number (Bi), where surface convention resistance was found lower in bagasse and phragmites with increasing drying time as compared to the internal resistance to heat transfer through thermal conduction into the material. Thus, it can be shown that Biot number increases as drying time increases in both agricultural residues. The bagasse and phragmites fibres had lower internal thermal conductivity and specific heat capacities, on the other hand both samples showed externally more heat flow resistive with respect to increasing drying treatment time, it was also endorsed by previous literature (El-Sayed and Mostafa 2016). While grapes and green chilies displayed comparable values with no discernible difference in Biot number values. Drying process comprising simultaneous heat and mass transfer between the surface of the material and the surrounding media, and a transfer of heat and moisture within the material. The transfer of moisture from the interior layer of the material to its surface depends on the structure and the properties of the material. drying depends upon the rate at which the moisture within the product moves to the surface by a diffusion process depending upon the material to be dried (Hossain and Bala 2007). It was observed that green chillies ad grapes had similar resistance to heat flow through convention and conduction with both treatment methods. Therefore, it is worthwhile to mention that drying behaviour of different materials depends on the nature, shape and size of the elements dried as well as the drying conditions as mentioned in the literature (Guiné and Lima 2020).

Table 5
Calculated mass transfer properties of drying agricultural energy crops and food crops

Drying time (hr)	Mass transfer properties of Bagasse							
	MR	K(s^{-1})	k_o	Di	Bi	μ_1	De (m^2/s)	h_m (m/s)
1	0.639	1.002×10^{-4}	0.916	5.170×10^{6}	0.075	0.404	2.682×10^{-8}	3.057×10^{-7}
2	0.533	2.947×10^{-5}	0.659	1.757×10^{7}	0.047	0.389	8.513×10^{-9}	6.133×10^{-8}
3	0.458	2.062×10^{-5}	0.573	2.511×10^{7}	0.041	0.386	6.059×10^{-9}	3.818×10^{-8}
4	0.414	1.245×10^{-5}	0.495	4.158×10^{7}	0.034	0.382	3.735×10^{-9}	1.948×10^{-8}
5	0.377	1.007×10^{-5}	0.452	5.142×10^{7}	0.031	0.380	3.044×10^{-9}	1.466×10^{-8}
Drying time (hr)	Mass transfer properties of Phragmites							
1	0.807	5.349×10^{-5}	0.979	9.686×10^{6}	0.060	0.396	1.494×10^{-8}	1.346×10^{-7}
2	0.501	8.510×10^{-5}	0.925	6.088×10^{6}	0.071	0.402	2.305×10^{-8}	2.471×10^{-7}
3	0.466	9.725×10^{-6}	0.518	5.327×10^{7}	0.031	0.381	2.942×10^{-9}	1.398×10^{-8}
4	0.151	8.753×10^{-5}	0.532	5.919×10^{6}	0.072	0.403	2.366×10^{-8}	2.564×10^{-7}
5	0.120	8.510×10^{-6}	0.140	6.088×10^{7}	0.030	0.380	2.586×10^{-9}	1.169×10^{-8}
Drying time (hr)	Mass transfer properties of Green Chilles							
1	0.942	1.617×10^{-5}	0.998	3.203×10^{7}	0.038	0.384	4.800×10^{-9}	2.761×10^{-8}
2	0.864	2.173×10^{-5}	1.010	2.384×10^{7}	0.043	0.387	6.367×10^{-9}	4.091×10^{-8}
3	0.755	3.026×10^{-5}	1.046	1.712×10^{7}	0.048	0.390	8.727×10^{-9}	6.348×10^{-8}
4	0.681	2.040×10^{-5}	0.914	2.539×10^{7}	0.042	0.386	5.995×10^{-9}	3.762×10^{-8}
5	0.607	2.056×10^{-5}	0.879	2.520×10^{7}	0.042	0.386	6.040×10^{-9}	3.801×10^{-8}
Drying time (hr)	Mass transfer properties of Grapes							
1	0.974	7.201×10^{-6}	1.000	7.195×10^{7}	0.028	0.379	2.200×10^{-9}	9.340×10^{-9}
2	0.948	7.201×10^{-6}	0.999	7.195×10^{7}	0.028	0.379	2.200×10^{-9}	9.340×10^{-9}
3	0.933	4.257×10^{-6}	0.977	1.217×10^{8}	0.023	0.376	1.320×10^{-9}	4.602×10^{-9}
4	0.893	1.114×10^{-5}	1.048	4.649×10^{7}	0.033	0.382	3.355×10^{-9}	1.678×10^{-8}
5	0.870	6.202×10^{-6}	0.973	8.354×10^{7}	0.027	0.378	1.903×10^{-9}	7.641×10^{-9}

Table 6
Statistical comparison of oven and solar drying of agricultural energy crops and food crops

Name of Sample	Treatment Time (hrs)	Moisture Content Removed % (Oven drying)	Moisture Content Removed % (Solar drying)	*t- value*	*p-value*	Remarks
Bagasse	1	11.37	14.71	-297.397	0.00001	Significant
	2	15.95	19.05	-95.422	0.00011	Significant
	3	24.12	22.07	29.152	0.00110	Significant
	4	25.72	23.90	68.150	0.00021	Significant
	5	26.06	24.38	51.861	0.00037	Significant
Phragmites	1	0.83	0.87	-3.1305	0.08867	Not Significant
	2	2.29	2.27	0.343	0.76420	Not Significant
	3	2.57	2.43	21.213	0.00221	Significant
	4	3.88	3.87	0.277	0.80755	Not Significant
	5	4.16	4.01	12.074	0.00678	Significant
Green chilles	1	7.76	4.01	530.330	0.00001	Significant
	2	12.34	9.41	415.778	0.00001	Significant
	3	19.16	16.83	156.270	0.00004	Significant
	4	23.56	22.10	129.244	0.00006	Significant
	5	29.28	27.11	195.432	0.00000	Significant
Grapes	1	1.49	1.36	19.788	0.00254	Significant
	2	2.17	2.73	-50.535	0.00039	Significant
	3	3.86	3.54	43.840	0.00052	Significant
	4	5.34	5.66	-43.840	0.00052	Significant
	5	6.85	6.84	1.141	0.29280	Not Significant

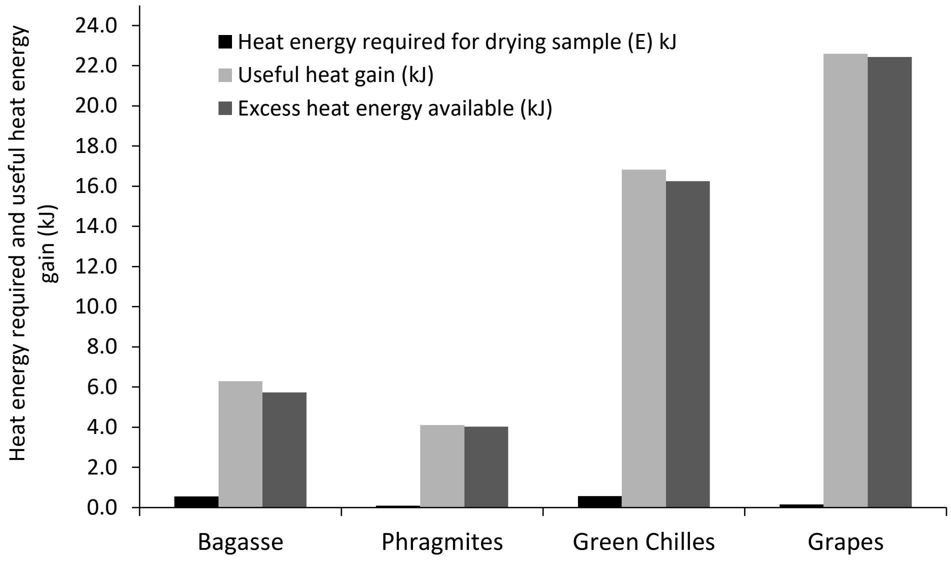

Fig 4 Heat energy required for drying unit mass plotted against useful heat energy gain by solar collector

3.5. Statistical Analysis

Table 6 depicts the statistical comparison between the solar and oven drying of food crops and agricultural energy crops. Bagasse drying showed that oven drying was having a significant effect on removing moisture content from the biomass. Drying of Phragmites showed that the solar drying method was had a pre-dominating significance at treatment times of 1, 2, and 4 hrs. Now, looking at the food crops, grapes and green chilles which were oven dryed had significant *p-values* for removing moisture content, while grapes dryed using solar drying showed significance at 5 hrs of treatment time.

4. Conclusion and Future work

This research investigation involved comparing two drying techniques i.e., cabinet solar dryer and conventional oven with 1 to 5 hrs of treatment times at temperatures of 45 ± 5 ^{o}C for agricultural energy crops and food crops. The moisture content in agricultural energy crops was reduced by both drying treatments which increased their corresponding HHV for their beneficial utilization in bio-power generation sector. Similarly, the food crops showed impressive results of moisture removal to keep the food crops away from getting spoiled by microorganism's decaying activity. Drying of food crops showed increasing trend of carbohydrates content with respect to increasing treatment times. With increasing treatment times, both treatment techniques showed decrease in protein, fat and vitamin C contents. The statistical results showed the oven drying method is more efficient as compared to the solar drying method. Similarly, the amount of heat energy required / kg of bagasse were 0.476 kJ/kg (oven) and 0.556 kJ/kg (solar), for phragmites it was 0.074 kJ/kg (oven) and 0.092 kJ/kg (solar), for chilles 0.524 kJ/kg (oven) and 0.576 kJ/kg (solar), and for grapes it was 0.123 kJ/kg (oven) and 0.157 kJ/kg (solar). Though the drying energy requirement of solar drying is higher than the oven drying treatment, the outcomes of solar drying are comparable to those of oven drying with only minor differences. Solar drying of food crops retains their nutritional values, which increases the quality of dried food and its utilization in off seasons. Solar drying is an environmentally friendly method based on solar thermal energy for its application in drying agricultural energy crops and food crops. Moreover, further study can be conducted to utilize the excess energy available in solar drying treatment for other useful applications.

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References

Ahmed, A., S. Hidayat, M. S. Abu Bakar, A. K. Azad, R. S. Sukri & Phusunti, N. (2021) Thermochemical characterisation of Acacia auriculiformis tree parts via proximate, ultimate, TGA, DTG, calorific value and FTIR spectroscopy analyses to evaluate their potential as a biofuel resource. *Biofuels*, **12**(1), 9-20. https://doi.org/10.1080/17597269.2018.1442663

Ali, M. & Watson, I. A. (2014) Comparison of oil extraction methods, energy analysis and biodiesel production from flax seeds. *International Journal of Energy Research*, **38**(5), 614-625. https://doi.org/10.1002/er.3066

Almajidi, M. & Algubury, H. (2016) Determination of Vitamin C (ascorbic acid) Contents in various fruit and vegetable by UV-spectrophotometry and titration methods. *Journal of Chemical and Pharmaceutical Sciences,* **9**, 2972-2974.

Baini R., Lai J C H., Abdul Samat N.A., Rahman M.R. & Mohidi, NSA. (2018) Performance Evaluation of Solar and Oven Drying for Tropical Fruits. *International Journal of Advances in Scientific Research and Engineering*, **4**(12), 216-224. https://doi.org/10.31695/IJASRE.2018.33025

Carl Ivar Branden & Tooze, J. (1998) Introduction to Protein Structure New York, Garland Science. ISBN 9780815323051

El-Sayed, S. A. & Mostafa, MES. (2016) Estimation of Thermal and Kinetic Parameters of Sugarcane Bagasse and Cotton Stalks Dust Layers from Hot Surface Ignition Tests. *Combustion Science and Technology,* **188**(10), 1655-1673. https://doi.org/10.1080/00102202.2016.1193495

Elnamer, M., A. El-Sheikha, G. Mosad & Mohamed, N. (2018) Comparison of Drying Characteristics of Seedless Grapes (Vitis vinifera L.) Using Solar Dehydrator and Natural-Sun-Dehydration. *Journal of Soil Sciences and Agricultural Engineering,* **9**, 587-595. https://doi.org/10.21608/JSSAE.2018.36490

Guiné, R. P. F. & Lima M. J. (2020) Study of the drying kinetics and calculation of mass transfer properties in hot air drying of Cynara cardunculus. *Open Agriculture* **5**(1), 740-750. https://doi.org/10.1515/opag-2020-0062

Hoseney, R. C. (1984) Chemical changes in carbohydrates produced by thermal processing. *Journal of Chemical Education*, **61**(4), 308. https://doi.org/10.1021/ed061p308

Hossain, M. (2015) Design and Development of Solar Dryer for Chilli Drying. *International Journal of Research*, **2**(1), 63-78.

Hossain, M. A. & Bala B. K. (2007) Thin layer drying characteristics for green chilli. *Drying Technology,* **20**(2), 489-505. https://doi.org/10.1081/DRT-120002553

Irmak, S. (2019) Challenges of Biomass Utilization for Biofuels. Biomass for Bioenergy - Recent Trends and Future Challenges. A. E.-F. Abomohra. London, Intech Open. DOI: 10.5772/intechopen.83752

Izaora Mwamba, Karl Tshimenga, Jean-Kayolo, Laurette Mulumba, Gauthier Gitago, Christina Mputu Tshibad & Kanyinda, J. N. M. (2017) Comparison of two drying methods of mango (oven and solar drying). *MOJ Food Processing & Technology*, **5**(1), 240-243. https://10.15406/mojfpt.2017.05.00118

Jigisha K Parikh, S. A. Channiwala & Ghosal G. K. (2005) A correlation for calculating HHV from proximate analysis of solid fuels. *Fuel*, **84**(5), 487-494. https://doi.org/10.1016/j.fuel.2004.10.010

Koua, B. K., P. M. E. Koffi & Gbaha, P. (2019) Evolution of shrinkage, real density, porosity, heat and mass transfer coefficients during indirect solar drying of cocoa beans. *Journal of the Saudi Society of Agricultural Sciences,* **18**(1), 72-82. https://doi.org/10.1016/j.jssas.2017.01.002

Kumar, D. & Kalita, P. (2017) Reducing Postharvest Losses during Storage of Grain Crops to Strengthen Food Security in Developing Countries. *Foods*, **6**(1), 1-22. https://10.3390/foods6010008

Liu, Z. and Pan, J. (2017) A practical method for extending the biuret assay to protein determination of corn-based products. *Food Chemistry*, **224**, 289-293. https://10.1016/j.foodchem.2016.12.084

Mierzwa-Hersztek, M., K. Gondek, M. Jewiarz & Dziedzic, K. (2019) Assessment of energy parameters of biomass and biochars, leachability of heavy metals and phytotoxicity of their ashes. *Journal of Material Cycles and Waste Management,* **21**(4), 786-800. https://doi.org/10.1007/s10163-019-00832-6

Mohammed, G. H. (2013) Effect of Seamino and Ascorbic Acid on Growth, Yield and Fruits Quality of Pepper (Capsicum Annum L). *International Journal of Pure and Applied Sciences and Technology*, **17**(2), 9-16.

Mohammed, S., M. Edna & Siraj, K. (2020) The effect of traditional and improved solar drying methods on the sensory quality and nutritional composition of fruits: A case of mangoes and pineapples. *Heliyon*, **6**(6), e04163. https://doi.org/10.1016/j.heliyon.2020.e04163

Grewal, P.S., Singla, M., Kaur, P., Manpreet Singh, M., & Kumar, A. (2017) Quality changes in fresh green chillies (Capsicum annuum L) under modified atmospheres. *International Journal of Chemical Studies,* **5**(5), 332-336.

Reis R.C., , V. C. Castro V.C, ;, I. A. Devilla, I.A, ; C. A. Oliveira, C.A, Barbosa, L.S, & Rodovalho, R. (2013) Effect of drying temperature on the nutritional and antioxidant qualities of cumari peppers from Pará (Capsicum chinense Jacqui). *Brazilian journal of Chemical Engineering*, **30**(2), 377-384. https://doi.org/10.1590/S0104-66322013000200011

Raitila, J. & Tsupari, E. (2020) Feasibility of Solar-Enhanced Drying of Woody Biomass. *BioEnergy Research*, **13**(1), 210-221. https://doi.org/10.1007/s12155-019-10048-z

Lokhande, S.M. & Sahoo, A.K. (2016) Effect of Drying on Grape Raisin Quality Parameters. *International Journal of Innovative Research in Science and Engineering* **2**(7), 86-95.

Saghir, M., S. Zafar, A. Tahir, M. Ouadi, B. Siddique & Hornung, A. (2019) Unlocking the Potential of Biomass Energy in Pakistan. *Frontiers in Energy Research*, **7**(24), 1-18. https://doi.org/10.3389/fenrg.2019.00024

Salunke, V.V., Deshmukh, K.B, Garud, R.P., Patil, A.S. & Kulkarni S.C. (2017) Improvement of Boiler Efficiency Using Bagasse Dryer. *International Research Journal of Engineering and Technology,* 4(10), 1286-1289. ISSN: 2395-0056

Sarkiyayi, S. & Agar, T. (2010) Comparative Analysis on the Nutritional and Anti-Nutritional Contents of the Sweet and Bitter Cassava Varieties. *Advance Journal of Food Science and Technology*, **2**, 328-334. https://maxwellsci.com/print/ajfst/v2-328-334.pdf

Srigley, C. T. & Mossoba, M.M. (2016) Current Analytical Techniques for Food Lipids. *Food Safety:* 33-64; Scrivener Publishing LLC. https://doi.org/10.1002/9781119160588.ch3

Takahashi, M., Ohshiro, M., Ohno, S., Yonamine, K., Arakaki, M., & Wada, K. (2018) Effects of solar- and oven-drying on physicochemical and antioxidant characteristics of hihatsumodoki (Piper retrofractum Vahl) fruit. *Journal of Food Processing and Preservation*, **42**(2), 1-9. https://doi.org/10.1111/jfpp.13469

Udomkun, P., Romuli, S., Schock, S., Mahayothee, B., Sartas, M., Wossen, T., Njukwe, E., Vanlauwe, B., & Müller, J. (2020) Review of solar dryers for agricultural products in Asia and Africa: An innovation landscape approach. *Journal of Environmental Management*, **268**, 1-14. https://doi.org/10.1016/j.jenvman.2020.110730