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A Comprehensive Review on Greenhouse Drying Technology

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Authors' contributions

This work was carried out in collaboration among all authors. Author AD Planned the review article and prepared the structure. Author AS collected the relevant papers. Authors PM and MKC helped in preparation of the manuscript. Author SSR read, corrected the manuscript and suggested vital inputs to the manuscript. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Drying is one of the most important unit operations for food preservation and storage. It is a energy intensive process and with the increase in the price and demand of electricity, renewable energy (solar) is proving its worth. Greenhouse dryers are low cost, easily constructible and can be utilised for invariably majority of agricultural commodities. The above attributes accounts for its high popularity in the Indian sub continents and Africa. An attempt has been made to generate a comprehensive review on the application, advances in construction, modelling, simulation and economics of the solar greenhouse dryers.

Keywords: Green house drying; renewable energy; agricultural drying.

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1. INTRODUCTION

Drying is considered to be one among the most efficient methods used to preserve food products [1]. In developing nations such as India open sun drying is the most commonly used method for drying of agricultural commodities. Sun drying, despite of being the most economical method faces severe limitation of uncontrolled drying because of lack of control over the external drying parameters such as heat input, moisture contents, temperature, drying air flow rate etc. The quality of final dried product in sun drying is also degraded due to wind-blown, debris, rain, insect and animal infestation [2]. A solar dryer is basically an enclosed unit which utilises solar energy for drying meanwhile keeps the food safe from damage, birds, insects, and unexpected rainfall. The food dried using solar dryer is dried in a cleaner and healthier way. The controlled conditions of temperature and moisture removing rate in solar drying ensures perfect drying and desirable product quality. Solar dryers are mainly classified as direct, indirect and hybrid solar dryers [3].

The greenhouse solar dryer basically comes under the category of direct solar drying and sometimes mixed mode solar drying system. Greenhouse is defined as an enclosed structure which works on the principle of trapping the solar radiation of shorter wavelength. Long wavelength solar radiation in the form of infrared radiation is emitted by earth's surface and gets stored inside the greenhouse increasing the temperature inside the greenhouse structure. This structure can be used to perform multitask including crop cultivation, soil solarisation, poultry farm, aquaculture etc. Low-temperature drying is ideal for vegetable and cash crop drying and it can be easily achieved in greenhouse structure. The solar greenhouse can be operated under natural convection mode as well as forced convection mode depending upon the amount of moisture to be removed and the product to be dried. In green house dryers the product is placed on trays receiving solar radiations through plastic covers and the moisture is removed by natural or forced convection [4,5]. The choice of the greenhouse cover is guided by cost, the need for long-term ultraviolet stability, strength and durability, high heat retention, low vapour condensation and light transmittance [6]. The UV stabilized plastic film which are IR inhibiting are the preferred films with wide application in India due to their low costs. The UV (150 μ) stabilized PVC films come in thickness of 150 to 1000 microns and have lifespans of 3 to 4 years. Thicker films have lower heat losses compared to thinner films but impede light transmission. Rigid Plastics include fiberglass, acrylic, and polycarbonate which come in corrugated and flat forms and are tempered to resist shatter. In the long term, they are more cost effective than the PVC films. Acrylic materials transmit light better than polycarbonate but the later are stronger and more resistant to impact and fire. Plain fiberglass has been found to yellow with time. This limits light transmission necessitating the use of PVC film coated fiberglass. Tempered glass panes are the ideal greenhouse covering materials. They are very strong and impact-resistant, and can withstand expansion and contraction during seasonal temperature changes. Single-pane thickness of 3 mm is adequate for greenhouses, but 4 mm thickness is stronger and provides additional insulation value. Tempered glass is more expensive than polycarbonate panels, but it is more durable and scratch-resistant. In green houses of bukura system the application of dual layers of 400 micron clear polyethylene film, enclosing an insulating air space of 19 mm to 100 mm thick in-between the outer UV stabilized and the inner IR film was found to reduce heat losses by 30 per cent [7]. The dual film relies on admitting about 80% of the incident sunlight; which is 10% lower than glass, minimizes temperature loss due to wind and thermal conduction to the outside and restricts heat loss by radiation in clear cloudless nights [8]. Radiation and ventilation provide two major functions of temperature and moisture control. High ventilation lowers the highest achievable temperature within the greenhouse, while too low ventilation allows high temperatures but results in poor moisture removal which in turn slows the drying. A hybrid photovoltaic-thermal integrated greenhouse dryer by integrating a greenhouse and PV modules that produce DC electrical power to operate a fan for forced mode operation and also provides thermal heating to the greenhouse environment. The UV stabilized polyethylene sheet fixed over the structural frame of the dryer helps in trapping infrared radiation and fans were used to obtain forced convection of air [9].

For the efficient operation of the greenhouse dryer the selection of suitable shape and orientation are the key factors. The even span roof and Quonset shape are the most commonly used shapes for green house dryer construction. In order to achieve maximum exposure to the sunlight the orientation of a greenhouse dryer is kept in east- west direction.

Table 1. Researches related to common shapes of the green house dryers

Sl. No.	References	Shape	Remarks
1	[10]	Geodesic dome	The geodesic dome solar greenhouse dryer was designed and tested for drying grapes under natural and forced modes
2	[11]	Mansard roof	A low cost solar active water heating system was designed to raise the night temperature and avoid freezing inside the greenhouses
3	[12]	Chapel shaped	The effect of nocturnal shutter and the heat provided by a solar air heater with a latent heat storage collector inside a chapel shaped insulated greenhouse was studied.
4	[13]	Semi cylindrical roof	A semi cylindrical roof solar greenhouse was proposed for drying of pork in the climatic conditions of Thailand
5	[14]	Even span, uneven span, modified IARI	The uneven-span greenhouse was proposed for effective heating of the greenhouse.
6	[15]	Modified arch	A novel hybrid solar energy saving system inside a heated polyethylene modified arched greenhouse was developed
7	[16]	Sandwich green house	A forced convection sandwich greenhouse for drying of rubber sheets was proposed
8	[17]	Single slope green house	A solar air heater to heat the greenhouse air temperature was presented

2. APPLICATION OF GREENHOUSE DRYERS FOR VARIOUS COMMODITIES

The green house dryer finds wide range of applicability in drying of various commodities from fruits and vegetables, spices and condiments to products such as khoa and papad. The product dried in the green house solar dryer is of better quality. The wider applicability of the green house dryer and ease of construction makes it one of the most popular technologies for drying in sub-tropical and African nations.

2.1 Fruits and Vegetables

Excess moisture present in the fruits and vegetables are removed by drying in order to enhance their shelf life and add value to them. Numerous researches have been conducted on applicability and suitability of greenhouse dryers for drying of fruits and vegetables. A greenhouse dryer with concrete floor of area $5.5 \times 8.0\ m^2$ covered with transparent poly carbonate plates and three fans powered by a 50 watt solar cell module was developed. It was found that 50 kg of fresh bananas with the initial moisture content of 70% can be dried in 3 days. With the same weather conditions, natural sun drying required 5 days of drying time. The air temperature inside the dryer at noon time of a clear day was 60-70ºC [18]. The thermal behaviour of cabbage and peas for green house dryer and sun drying was studied for development of drying models. The developed models were validated with experimental data and were found in good agreement with coefficient of correlation ranging between 0.77 and 0.97 for the crop and greenhouse room air temperatures and 0.98-0.99 for the crop mass during drying [19]. Performance of greenhouse dryer was analysed for Thompson seedless grape variety compared to natural drying and shade drying. The convective mass transfer coefficient for greenhouse dryer was found to have lower value compared to open sun drying and the product dried inside the greenhouse dryer had superior quality and colour as compared to that in naturally dried products [9]. Polythene covered large scale solar greenhouse dryer with parabolic roof and polyethene sheet was developed and its performance was evaluated. The dryer had width of 7.5 m, length of 20.0 m and height of 3.7 m, with a loading capacity of about 1,000 kg of fresh fruits or Vegetable. The drying time was found to reduce by 3-4 days for chilli and banana and the drying temperature varied from 35-64ºC. A system of partial differential equations describing heat and moisture transfer during drying of chilli and banana inside the solar greenhouse dryer was developed and this system of non-linear partial differential equations was solved numerically using the finite difference method. The numerical solution was programmed in Compaq Visual FORTRAN version 6.5. The simulated results agreed well with the experimental data for solar drying of chilli and banana [20]. In order to study the thin layer drying characteristic of organic tomato in a solar tunnel greenhouse dryer in the climatic conditions of Ankara, Turkey tomatoes were dried from initial moisture content of 93.35% (w.b.) to final moisture content of 11.50% (w.b.) in 4 d in solar greenhouse tunnel dryer as compared to 5 d in open sun drying mode. The dried product was reported to be protected from insects, birds, rain and dusts [21]. Studies were conducted to determine the effect of mass on convective mass transfer coefficients for various masses of onion drying under OSD, natural and forced convection greenhouse drying modes. The values of convective mass transfer coefficient for onion were found to vary from 1.19 -2.75 $W/m^{2o}C$, 1.28-2.28 $W/m^{2o}C$ and 1.09-3.08 $W/m^{2o}C$ under OSD, natural and forced convection greenhouse drying modes respectively [22]. The conventional greenhouse was improved by using inclined north wall reflection for faster drying of bitter gourd slices under natural and forced convection modes. The air temperature inside improved greenhouse under natural and forced convection modes were reported to be increased from 1ºC to 6.7ºC and 1ºC to 4ºC respectively [23]. The convective heat and mass transfer coefficient for green chilli drying under open sun and under forced convection greenhouse drying mode were determined. Chilli was blanched with sodium hydroxide and sodium chloride solution. The values of Convective heat and mass transfer coefficient were found to be 4.333 $W/m^{2o}C$ and 5.520 $W/m^{2o}C$ for green chilli drying under forced Convection Greenhouse dryer blanched in sodium hydroxide and sodium chloride respectively [24]. A low cost greenhouse dryer was developed for the drying of onion. Onion slices were pre-treated before drying sodium chloride and potassium metabisulphite. The thermal efficiency of greenhouse dryer was found to be 20.82% [25]. A large scale modified greenhouse dryer (black concrete floor) having loading capacity of 1000 kg. Chilli, banana and coffee were used to dry inside the modified greenhouse dryer from initial moisture content of 75% (wb) in 3 days, 68% (wb) in 5 days and 52% (wb) in 2 days as compared to 5 days, 7 days and 4 days in open sun drying conditions respectively. The payback period of the dryer was estimated to be 2.5 years. Studies were conducted to determine the effect of nocturnal shutter and the heat provided by a solar air heater with latent heat storage collector inside an insulated greenhouse. Tomato crop was planted in two identical greenhouses (with and without nocturnal shutter) for comparison purpose. Temperature inside the greenhouse with nocturnal shutter was reported to be 2ºC higher than the greenhouse without nocturnal shutter. The radiation heat loss rate was reported to be 24% and 61% of the total losses in insulated greenhouses with and without shutter respectively [12,18]. In order to study the effect of architectural form of greenhouse solar dryer on drying of onion flakes air was pushed naturally through the holes under the greenhouse solar dryer passing through the agricultural products to carry out the moisture and moving it through the chimney which is installed at the top of the greenhouse solar dryer. There were two experimental operations; the first one was without using rocks, the second one with rocks to raise the drying efficiency. The period of drying without rocks takes 45 hours but it takes 42 hours by rocks. The resulting efficiency ranged between 57-72% for all dryers without rock and with rock. The maximum moisture content removed from 81.2% to 12.05%, from 81% to 12.09% and from 81.2% to 14.7% without rock but it was removed from 80.02% to 8.67%, from 78.33% to 10.14% and from 78.59% to 13.55% with rock for the three solar dryer (SD_1), (SD_2) and (SD_3) respectively. The total incident solar energy are 39.75, 36.96 and 32.62 kW for the three solar dryers without rock, respectively, while the three solar dryer with rock gave 46.06, 41.41 and 40.50 kW, respectively [26]. A photovoltaic powered greenhouse dryer was developed for drying studies of red chilli. The red chillies was dried from an initial moisture content of 63.8% (w.b.) to a final moisture content of 8.01% (w.b.) over a time period of 5 days in the forced ventilated solar greenhouse dryer. It took nearly 8 days for reducing the moisture content of red chillies up to same level. The quality of red chillies produced from the solar tunnel greenhouse dryer was found to be superior to open sun drying method [27]. For studying the drying behaviour and effect of mass on convective heat transfer coefficient for onion flakes drying under open sun and greenhouse drying modes, onion flakes were continuously dried for 33 h both in open sun and in roof type even span greenhouse with floor area of 1.2 m×0.78 m. It was observed that the convective heat transfer coefficient increased by 30–135% as the mass of the onion flakes was increased from 300 to 900 g for different drying modes [22]. A large scale greenhouse dryer with LPG burner was developed and investigated for drying osmotically dehydrated tomato. Solar drying of osmotically dehydrated tomato in solar greenhouse dryer resulted in considerable reduction in drying time compared with open air sun drying. The quality of the products dried in the solar greenhouse dryer was reported to be better as compared to the open air dried products [18]. Drying behaviour of Sultanite grape variety under three different solar grapes drying processes i.e. open sun drying, natural convection solar dryer and solar tunnel greenhouse drying mode were studied [28]. Two different drying methods of greenhouse dryer and open sun drying were compared for drying of plums and greenhouse solar dryer was recommended better among the two [29]. Walk-in type hemi cylindrical solar tunnel dryer with heat protective north wall to dry seedless grapes was developed [30]. The effect of different solar dryers on vitamin content of tomato (Solanum lycopersicon) was studied and the results showed a significant difference in the concentrations of vitamins A, C and E between the fresh and the dried samples for all drying systems. While Vitamins C reduced in concentration for all dried samples, Vitamins A and E increased significantly with open-air system having the highest value in vitamin C concentration while latitudinal box dryer gave the best result in terms of vitamins A and E retention [31].

2.2 Fish and Meat Products

A forced convection greenhouse dryer can be used efficiently for drying of products with high moisture content such as fish and meat products. A greenhouse type solar tunnel dryer (collector area of 150.9 m^2) for industrial drying of selected species of fish croaker, anchory and ribbon was fabricated. The design mainly included single span arc type G.I pipe frames and single layer 200 micron thick UV stabilised polyethylene sheet. The moisture content of salt treated fish reduced up to 42.85% to 66.66% (db) between 8 to 16 h, whereas in case of unsalted fish moisture content was reduced up to 17.64% - 25% (db) in 24 to 32 hours of drying depending on the variety of fish and initial moisture content. Lower drying temperature drying was found to offer better quality to the final dried product [32]. A greenhouse dryer with heat exchanger was developed in order to improve its efficiency and was tested for salted catfish at average solar radiation of 626 W/m^2. The dryer majorly consisted of the heat pipe evacuated tube collector, electric heaters, blower, pumps, water tank, and green house drying chamber. The average temperature of the drying chamber was 44ºC with the drying time of 18 h (8 h day time and 10h night time). The total energy required used is 294.98 kWh and the solar energy contribution was 60% of the total energy. The moisture extraction rate and specific moisture extraction rate obtained were 6.3 kg/h and 0.385 kg/kWh, respectively. The values for exergy efficiency varied between 29% and 82% with an average of 46%. Economic analysis showed that system has a payback period of about 1 year [33]. The comparative study for drying of pork under open sun and solar greenhouse drying was carried out and green house drying was found comparatively superior [12].

2.3 Flowers and Spices

Drying of flowers and spices involves retention of flavour and texture after drying and can be dried at lower temperatures in a greenhouse dryer. Performance of a novel mixed mode solar greenhouse dryer with forced convection for the drying of red pepper and sultana grape was conducted A flat plate collector was integrated with the greenhouse to increase the greenhouse air temperature. The moisture content of red pepper and Sultana grapes were reduced to 16% (wb) and 18% (wb) in 24 h and 50 h respectively [34]. The thermal modelling and experimental validation of a walk-in type solar tunnel greenhouse dryer for the drying of fenugreek leaves was presented. Fenugreek leaves were reported to be dried from initial moisture content of 89% (wb) to final moisture content of 9% (wb) in 17 h. Energy and exergy efficiencies were reported to vary 0.841% to 1.613% and 0.018% to 0.102% respectively [35]. Simulation of the drying process of chamomile flower was performed by using new TRNSYS model integrating equilibrium drying model and thin layer drying principles [36]. Experiments were conducted on greenhouse dryer to dry sweet pepper, results showed that double chamber greenhouse dryer was 87% more productive than single chamber for the same area [37]. (The natural and forced convection solar greenhouse dryer for drying of rewetted mustard was studied. Mustard was also dried in open sun for comparison during the study. A polyethylene natural convection greenhouse dryer was proposed for drying of pepper and the Passamai and Saravia’a model was applied for drying of pepper [28]. Two different types of natural circulation greenhouse dryer were designed and tested for pepper drying. The dryers were tested without load without chimney, with load (pepper) without chimney and with load (pepper)-with chimney. The experimental performance of solar drying of rosella flower and chilli using roof integrated solar dryer) was studied. Field level experiments for deep bed drying of both (rosella and chilli) were performed. Significant reduction in drying time in roof integrated solar dryer as compared to sun drying was observed [18]. Thin layer drying characteristics of red pepper by three different solar drying processes (under open sun, greenhouse and solar drier) were compared. Different thin layer drying models were used and among them the Logarithmic model was found to be the most suitable model for describing the drying curve [28].

2.4 Copra and Dates

Certain products such as copra and dates which have harder texture and high amount of moisture can be dried using forced convection greenhouse dryer. A greenhouse dryer with a semi-circular roof which was covered with a UV (200 μ) stabilized polyethylene film was developed and its numerical simulation was performed. The simulated solar greenhouse tunnel dryer reduces moisture of copra from 52.2% to 8% in 55 h under full load conditions. A system of partial differential equations describing heat and moisture transfer during drying copra in the solar greenhouse dryer was developed and solved using finite difference method. The numerical solution was programmed in Compaq Visual FORTRAN version 6.5. The simulated results reasonably agreed with the experimental data for solar drying copra [38]. Coconuts were dried from initial moisture content of 52% (wb) to final moisture content of 7% (wb) in 53, 66 and 78 h using rock-bed, sand and concrete respectively as compared to 174 h in open sun drying mode. The effect of various sensible heat storage materials (concrete, sand and rock-bed) on drying characteristics of coconuts and thermal performance of natural convection solar greenhouse for copra drying was studied. The drying efficiency was also reported to be 9.5%, 11% and 11.65% using concrete, sand and rock-bed respectively [39]. A natural convection solar tunnel greenhouse dryer coupled with biomass backup heater (when non availability of sunlight is there) was designed and developed to study the drying characteristics of coconuts. Coconut fronts, coconut husk and coconut shells were used as fuel for the biomass heater. Coconuts were dried from initial moisture content of 53.84% (w.b.) to final moisture of 7.003% (w.b.) in 44 h whereas 56 and 148 h were taken by the dryer without back up heater and open sun drying mode respectively. Coconuts dried in dryer were reported to be free from dust, dirt, damage by birds and infections by bacteria and fungus [40]. A new approach of utilizing a solar greenhouse (gable even span) as a solar air heater for drying dates was studied [41].

2.5 Miscellaneous Products

Apart from the major application of greenhouse dryers it can also be used for drying products such as vermicelli, khoa, papad etc. Behaviour of heat and mass transfer during forced convection greenhouse drying of papad has been investigated. Papad of 180 mm diameter and 0.7 mm thickness was prepared and papad of 23.5 g weight was taken for each run of drying. The average values of convective and evaporative heat transfer coefficients were reported as 0.759 $W/m^2{}^oC$ and 23.48 $W/m^2{}^oC$ respectively [42]. Effect of various shapes and sizes of jaggery for different mass (2.0 kg and 0.75 kg) on convective mass transfer coefficient was analysed. Sample size of 0.03×0.03×0.01 m^3, 0.03×0.03×0.02 m^3 and 0.03×0.03×0.03 m^3 as thin layers were used for the experimentation Further the results were improved by generating ANFIS (adaptive-network-based fuzzy inference system) to predict the jaggery temperature, the greenhouse air temperature and the moisture evaporation for drying of jaggery inside the greenhouse under natural convection mode [43]. The convective heat transfer coefficients for khoa pieces were evaluated in a controlled environment under natural and forced convection greenhouse and open sun drying modes which were found to vary from 0.54-0.91 $W/m^2{}^oC$, 0.86-1.09 $W/m^2{}^oC$ and 0.54-1.03 $W/m^2{}^oC$ respectively. An empirical model was also developed to predict the convective heat transfer coefficient for khoa as a function of drying time. 100 g of khoa sample of 1.5 cm thickness was taken for the experimentation and dried till no variation in its mass was recorded [44].

A MATLAB-based modelling and simulation system to predict the air flow properties, equilibrium moisture content of the solar dryer technology was developed. Moisture removal process was analysed for seven days and 7% of weight reduction was observed. The performed on mat lab program and the 3-D model has been developed on process. The Crank-Nicholson equation has been applied to heat and finite difference method has been used to develop for drying cocoa bean. This results show a time of drying reduces the moisture contains for 50% to 7% and 60% to 8% of moisture removal of dried bean [45].

3. ENERGY AND EXERGY ANALYSIS OF GREENHOUSE DRYERS

The main aim in an effective drying process is to remove the maximum moisture from the products reaching its safe level and utilise the minimum amount of energy. Energy and exergy analysis for the performance of photovoltaic/thermal (PV/T) integrated greenhouse in the climatic conditions of Delhi, India. The exergy efficiency of PV/T integrated greenhouse was found to be 4% [46]. Exergy efficiencies were derived as a function of drying time and temperature of the drying air. The average exergy efficiency of drying process was reported to be 63%-73 per cent. The solar heated greenhouse was proposed for pre-drying during low solar energy gain [47]. The energy analysis of greenhouse dryer for drying of kasturi methi (fenugreek) leaves and values of energy efficiency and exergy efficiency was 2.72-28.01% and 69.43-90.76 % respectively [35]. Analysis of jack fruit leather drying and obtained the values of 48.21% and 41.42% for energy and exergy efficiencies respectively [48].

4. SIMULATION OF THE GREEN HOUSE DRYER

For mathematically model of greenhouse solar dryers with natural convection: mechanistic, empirical and numerical are mainly used. Mechanistic models, also called theoretical, are based on first principles, particularly in the mass and energy transfer processes that are carried out during drying and in the greenhouse-dryer environment. The model, the change in the air temperature with respect to time inside the dryer, the product, the ground and the cover, in addition to the change in the moisture content of the product during the dehydration process [5,49]. Some studies report the convective heat transfer coefficient as an important parameter in the simulation of the drying rate, since the temperature difference between the air and the product varies with this coefficient [50]. Drying kinetics can be effectively described using transport properties together with a drying constant defined by a thin layer equation are used in agricultural products [51]. Various thin layer models have been used to study the drying kinetics of amaranth [52], coconut [53], red pepper [49] and tomato [54,55]. Fuzzy logic-based models are not commonly used to model the climate of solar dryers instead neuro-fuzzy models combine the advantages of fuzzy logic systems with artificial neural networks. The spatial models represented by a set of differential equations in partial derivatives, for several variables of the system are mostly used for carrying out integral balances of matter and energy [56]. Yelmen, 2018 examined working parameters of the framework comprising of air warmers and dryer with sun based vitality of 0.20 m^2 with a space of 0.72 m^2 and 10 pieces in the lodge were researched tentatively. Average climatic air temperature and relative humidity during the dry sunlight hours were estimated at 49ºC and 35%, separately [57]. Because of the assessment of the test outcomes, the atmospheric air temperature of 56ºC was come to in the dryer relying upon the sun powered radiation and environmental conditions. Six different models and MBE, RMSE and t-stat comparison methods were used to calculate the amount of global solar radiation on the horizontal surface. The best results were given by Model-3 with values of MBE=0.130 and RMSE=1.401, while the best result from t-statistics was with t-ist=0.282 with Model-5. Twelve distinctive numerical models for red pepper plant (*Capsicum annum* L.) were analysed. This study endeavoured to survey the proficiency and gainfulness of the drying of red pepper under the plastic tunnel greenhouse and an aggregate of twelve models, including Newton, Page, Improved Page, Henderson and Pabis, Logarithmic, Wang and Singh, Diffusion, Two-Term Exponential, Two-Term, and Simplified Fick Diffusion, were assessed. The drying procedure was done in three distinct periods. During every application period, separate drying trials were completed for the item densities of 2, 3, 4, and 5 kg/m^2. It was determined that the most appropriate mathematical model with the highest expression coefficient (R^2) was the Two-Term model given an equality of $(M_t / M_o) = a \exp(-k_1 t) + b \exp(-k_2 t)$. When the coefficients of model, model coefficients and calculated values were compared with experimental data, the highest expression coefficient was obtained with Two-Term model and was at 0.9886-0.9977 [58]. These simulation studies and model fittings allows us to predict the drying behaviour of various products in the green house dryer.

Table 2. Studies on economics of greenhouse dryers

Sl. No	Product	References	Payback period (years)	Estimated life of dryer (y)	Remarks
1	Macadamia	[59]	-	1	Loading capacity was 750 kg.
2	Chilli, banana	[18]	2.5	2.5	Maximum capacity estimated was 1000 kg
3	Pork	[12]	1.15	-	Maximum capacity of dryer was estimated to be 40 kg
4	Strawberry	[60]	-	-	The benefit-cost ratio was found to be 1.74.
5	Fenugreek	[61]	22 days	-	Loading capacity of dryer was estimated to be about 100 kg

5. ECONOMIC ANALYSIS OF THE GREEN HOUSE DRYER

It is very important to study the economic aspects in order to know the importance and utilization of greenhouse dryers. The temperature inside the greenhouse can be maintained to the optimum level for a given crop or product for higher yield. Greenhouse drying earns more profit as compared to traditional open sun drying because of better quality of the final dried product and also reducing the drying time. The life cost of a dryer mainly depends on Initial investment and operating cost of greenhouse and maintenance cost of greenhouse various factors [62]. The economic analysis of greenhouse dryers can be mainly performed using three methods such as annualized cost, life cycle savings and payback period [46]. The major costs of the solar dryer are of the solar greenhouse dryer system and the drying trays. The parameters calculated for detailed financial analysis mainly include discount rate, inflation rate and project lifetime Annualized cost method aims at finding out the cost of drying for unit weight of the product. The annualized drying cost of a solar dryer is almost constant over the entire life of the drying system. Life cycle savings method calculates the savings made in the future years and also to make the present worth of annual savings over the life of the system. Payback period method gives the investment's return period, and hence, helps to determine the acceptability of the technology.

6. CONCLUSION

There has been considerable research performed on the shapes and applicability of greenhouse dryers. Green house dryers find wide range of applicability ranging from fruits and vegetables to products such as copra, studies on economics of greenhouse dryers and even meat. Forced convection greenhouse dryer is mostly used for product with high initial moisture content. Numerical simulation methods have been extensively used and developed in order to study the parameters affecting drying and achieve effective drying. Product dried in the green house dryers has better quality as compared to sun dried products. Green house dryers find wider application in Southeast Asian countries including India. They are found to have lower cost of construction, operation and maintenance as compared to mechanical dryers.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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