Chapter 7

Conclusion and Future Scope

7.1 Conclusion

An experimental set-up for the drying of *Garcinia pedunculata* and *Curcuma amada* was developed at Tezpur University, India. The experiments were conducted at a location of latitude 26°42' 03″ N and longitude 92°49'49″ E. The experiments were performed in free convection corrugated type of solar dryer, indirect solar dryer without and with storage and mixed mode solar dryer without and with storage. Additionally, another set of experiments were carried out to evaluate the effectiveness and viability of the solar dryer by considering the indirect mode with a can-integrated solar air collector.

7.1.1 Evaluation of a free convection corrugated type of solar dryer for Garcinia pedunculata: An investigation on kinetics, energy, and economic aspects

The thin layer drying kinetics of *Garcinia pedunculata* (GP) were investigated under OSD and in a free convection corrugated solar dryer (FCCSD) with mathematical modeling. Ambient temperature and relative humidity during drying varied within specific ranges for both batches. In FCCSD, the inlet and outlet temperatures, along with relative humidity, were recorded. The integrated solar air heater showed an average useful heat gain of 289.31 W and 290.36 W, with average thermal efficiencies of 33.29 % and 33.33 % for the first and second batches, respectively. The Midilli and Kucuk model was identified as the most suitable for FCCSD, and the Two-Term model for OSD in both batches. FCCSD reduced GP MC from 88 % (w.b.) to 7.22 % (w.b.) and 7.1 % (w.b.) in 28 h for the first and second batches, respectively. OSD achieved final MC of 10.18 % (w.b.) and 10.08 % (w.b.) for the first and second batches in 55 h. The average thermal efficiency of the dryer was 10.69 % and 10.77 %, with specific energy consumption of 68.00 $kWhkg^{-1}$ and 65.54 $kWhkg^{-1}$ for the first and second batches, respectively. Economic analysis indicated an annual savings of $ 253.24 and a payback period of 0.6 years for FCCSD, suggesting potential commercialization for farmers. The FCCSD production capacity was estimated at 0.850 kg per batch, with scalability for increased total production in the future.

7.1.2 Evaluation of a PV-driven innovative solar dryer with and without sensible heat storage for *Garcinia pedunculata*: An investigation on kinetics, energy, and economic aspects

The study introduces a novel active solar dryer designed for indirect and mixed modes, presenting its performance in drying *Garcinia pedunculata* (GP) along with drying kinetics and economic analysis. Four sets of experiments were conducted, involving indirect and mixed-mode solar drying with and without sensible heat storage (SHS). Key findings include the observation that, during 17:00-18:00 h, the solar air heater with SHS exhibited an output temperature 2.5-6.7 °C higher than ambient temperature due to heat stored in SHS materials. The maximum efficiencies of the solar air heater without SHS ranged from 71.79 % to 73.34 %, while with SHS, efficiencies reached 83.56 % to 85.52 %. The average efficiencies of the dryer in different experiments ranged from 18.12 % to 24.46 %, with the mixed-mode solar dryer with SHS (Exp. IV) demonstrating the highest efficiency. The specific energy consumption was lowest in Exp. IV at 5.33 kWh/kg. In all experiments, GP MC decreased from 87.99 % to 12.09 % (w.b.) with drying times ranging from 10 to 53 h. Drying models were evaluated, with the Two-Term model fitting best for Exp. I, Exp. II, OSD, and Exp. III, while the Midilli and Kucuk model was optimal for Exp. IV. Economic analysis revealed construction costs for the dryers and attractive payback periods, ranging from 0.59 to 1.6 years, showcasing the economic viability of the developed solar dryer.

7.1.3 Evaluation of a PV-driven innovative solar dryer with and without sensible heat storage for *Garcinia pedunculata*: An investigation on exergy and environmental aspects

The exergy and environmental impact of a solar dryer were analyzed, considering four configurations: indirect-mode solar dryer without storage (ID-WOS), mixed-mode solar dryer without storage (MX-WOS), indirect-mode solar dryer with storage (ID-WS), and mixed-mode solar dryer with storage (MX-WS). The final MC decreased to 12.8 % (w.b.) in 30 h for ID-WOS, 25 h for MX-WOS, 28 h for ID-WS, and 8 h for MX-WS from an initial 87.2 % (w.b.). Notably, the solar air heater (SAC) with sensible heat storage (SHS) proved more effective than without SHS at the same mass flow rate, with higher efficiency observed after 12:30 h. Exergy studies revealed that the wavy collector had relatively low exergy efficiencies due to losses from various components, while the drying chamber exhibited high exegetic efficiencies toward the end of drying intervals. The average exergy efficiencies for ID-WOS, MX-WOS, ID-WS, and MX-WS were 47.08 %, 65.10 %, 52.46

%, and 68.07 %, respectively. Over a 20-year lifespan, CO_2 emissions and mitigation varied among configurations, and while the total embodied energy of mixed-mode was higher, the use of gravels as storage did not significantly impact CO_2 emissions, mitigation, or carbon credits. The anticipated energy payback periods (EPPD) were 1.47, 1.61, 1.48, and 1.62 years for ID-WOS, MX-WOS, ID-WS, and MX-WS, respectively, with MX-WS demonstrating superior performance across all factors.

7.1.4 Evaluation of a PV-driven innovative solar dryer for *Curcuma amada* without and with gravels as thermal energy storage: An investigation on kinetics, energy, exergy, quality and economic aspects

In this study, series of experiments aimed to assess the variability and practical implications of a solar dryer, combining indirect solar drying mode for *Curcuma amada* with a solar air collector (SAC) featuring a waste beverage can absorber plate and a sensible heat storage system using gravels within the SAC to extend operational duration beyond solar radiation h. The results demonstrated a significant reduction in drying time for *Curcuma amada* when storage was implemented, reaching an equilibrium moisture level of 4.4 % in just 8 h in the Solar Dryer with Collector and Storage (SDCWS), compared to 26 h in the Solar Dryer with Collector without Storage (SDCWOS). The Midilli and Kucuk model was identified as the most suitable fit for both experiments in drying kinetics. The observations indicated effective utilization of energy from the SAC, with peak efficiency of 91.55 % during declining solar radiation in the SDCWS mode. The SDCWS exhibited higher average efficiency (29.63 %) compared to SDCWOS (21.88 %), considering total energy utilization due to storage. Exergy efficiencies were 69.13 % for SDCWS and 54.50 % for SDCWOS, with elevated exergy efficiencies noted as drying periods ended. Quality analysis revealed that products dried using SDCWS preserved original color and texture better than those dried under SDCWOS. Economic evaluation indicated a payback period of 1.7 years for SDCWOS and 0.47 years for SDCWS, considering corresponding capital costs of 22,000 INR and 23,000 INR, respectively.

An experimental study was conducted at Tezpur University, India, on the drying of *Garcinia pedunculata* and *Curcuma amada* using various configurations of solar dryers to provide valuable insights into enhancing drying efficiency, reducing energy consumption and enhancing the quality of the products. The study covered diverse setups, including free convection corrugated solar dryers, indirect solar dryers with corrugated absorber plate SAC without SHS, mixed-mode solar dryers with corrugated absorber plate SAC without SHS, indirect solar dryers with corrugated absorber plate SAC with SHS, mixed-mode solar dryers with corrugated absorber plate SAC with SHS, indirect solar dryers integrated with canned absorber plate SAC without SHS, and indirect solar dryers integrated with canned absorber plate SAC with SHS. The drying kinetics varied for each setup, with drying times ranging from 8 to 31 hours. Notably, the mixed-mode solar drying with corrugated absorber plate SAC with SHS exhibited the shortest drying time of 10 hours for *Garcinia pedunculata*, while for *Curcuma amada*, the indirect solar drying integrated with canned absorber plate SAC with SHS achieved a remarkably short drying time of 8 hours. Thermal efficiency ranged from 10.77 % to 29.63 %. The highest efficiency was observed in the mixed-mode solar drying setup with corrugated absorber plate SAC with SHS for *Garcinia pedunculata*, and the lowest in the free convection corrugated type solar dryer for the same product. Economic analysis revealed attractive payback periods ranging from 0.47 to 1.7 years, highlighting the economic viability of the developed solar drying systems across different configurations and products. These research findings offer comprehensive insights into the feasibility, efficiency, and sustainability of solar drying technologies, providing valuable guidance for future developments and implementations in agricultural processing industries.

7.2 Future Scope

- Numerical simulations employing robust Computational Fluid Dynamics (CFD) tools should be employed to investigate the flow patterns within the solar dryer system. These simulations, along with flow visualizations, will provide valuable insights into the dynamics of the drying process. Additionally, the results of flow visualization can be further utilized for the design and enhancement of the dryer, thereby optimizing its performance and efficiency.
- Integrating various thermal energy storage unit can expedite the drying process and enhance the efficiency of the system.
- Optimization of the amount of storage material used and integration of an air distributor inside the drying chamber for uniform distribution of air inside the drying chamber could be researched in the future.
- The impact of a dehumidifier on improving the efficiency of the dryer can be explored.
- Integrating of photovoltaic thermal collectors into drying processes to guarantee operational functionality, particularly in agricultural fields can be further studied.