Sintie and Aduye *Renewables (2020)7:3*
https://doi.org/10.1186/s40807-020-00059-2

Renewables: Wind, Water, and Solar

ORIGINAL RESEARCH ARTICLE
Open Access

Potential assessment and experimental analysis of solar vegetable dryer: in case of northern Ethiopia

Yihun Tefera Sintie[1*] and Gebrie Teshome Aduye[2]

Abstract

The traditional vegetable drying (open-air/sun drying) method of harvesting of tomato, potato and onion in the Fogera District in Amhara regional state, Ethiopia, leads to loss of product, reduction in the quality of product and economic loss for the poor farmers. So, this experiment aimed to show the effectiveness of solar dryer technology by increasing the quality of the product in *tomato, potato, and onion in Fogera district Northwest Ethiopia, 2018*. A simple solar vegetable dryer is experimentally analyzed to alleviate the problem associated with vegetable processing in Woreta city. The first law of thermodynamics energy analysis was carried out to estimate the amount of useful energy gained from solar air dryer and energy utilization ratio of the drying chamber and the energy through drying box. The magnitude of the exergy inflow, outflow and exergy losses in the drying chamber during the drying process was determined by applying the second law of thermodynamics. The average solar drying efficiency was found to be 75.01% to 86.70% for tomato, 75.70% to 87.90% for potato and 58.7% to 85.5% for onion. Regrading the drying period, it took 33 h for tomato, 27 h for potato and 44 h for onion during the experimental test.

Keywords: Experimental analysis, Tomato, Potato, Onion, Solar drying

Introduction

In Ethiopia, especially in Fogera District in Amhara regional state, agricultural vegetable products like onion, potato and tomato share the biggest part of the country's economy (Wassie. 2016). About 80–90% of the population life depends on vegetable agriculture products (ILRI 2005). Existing evidence shows that vegetable production still does not meet the need of the population, although the production of crops such as onion, tomato and potato is increased from year to year. According to Fogera Agricultural office 2017 report, about 216,788-ton of tomato was produced per year in Fogera District. From this, more than half (55%) of the products had been lost during post-harvest processes. Similarly, 3,661,312.5 ton of onion is produced per year and from this 47% would be lost during post-harvest processes and 122,862.5-ton potato is produced per year and from this 32.3% would be lost during post-harvest processes (Appendix A). The lack of appropriate preservation and storage systems caused considerable losses and reduced the vegetable supply significantly (Karim 2004).

Drying is one of the most prevailing methods of food preservation (Mustayen et al. 2014), where the moisture is removed preventing the growth of microorganisms that causes food damage (Marketing of vegetables thesis first draft). It is also a process which combined heat and mass transfer, where the surface moisture is removed first and the moisture from the interior is forced to move to the surface, which is then removed later (I. S. U. N. Drying 2006). Traditionally, the local farmers utilize open sun drying system which may be responsible for the mentioned large post-harvest loss (Solar Dryer with V-Groove Solar 2013). Therefore, utilization of technology to reduce the post-harvest loss is essential. This can be done by using solar dryer technology. This technology

*Correspondence: yihuntefera03@gmail.com
[1] Department of Mechanical Engineering, Institute of Technology, University of Gondar, P.O. Box 196, Gondar, Ethiopia
Full list of author information is available at the end of the article

is unique in that the developed dryer has better turbulence effect which helps to remove the hot humidity of the drying system at each tray thereby to improve the preservation of the vegetables such as potato, tomato, and onion.

Solar dryer technology is a cost effective and feasible approached in minimizing the harvest loss and increasing the quality of the products (Soundy and Brutsch 2014, unpublished data). Using this solar vegetable drying technology is also crucial to yield high-quality marketable products which in turn can improve the economic situation of the farmers, assuring food security by minimizing vegetable product loss (Akpinar 2010).The performance of the solar dryer is significantly dependent on the weather condition. Solar dryers located in Fogera District area used solar energy to remove the moisture contained from the product. Therefore, the weather conditions have the biggest influence on the capacity of drying products that can be dried at a certain time. Then measurements of radiation components require expensive equipment that is costly to operate as well as maintain, reliable measurements are undertaken at only a limited number of stations. The solar radiation data can be used as an input variable of solar vegetable dryers. The effects of weather condition data as sources of the solar vegetable dryer before the experimental tests were recording temperature, horizontal radiation and drying humidity and summarized in Table 2 (Appendix B). Thus, data show before the experimental test that is similar to atmospheric condition. During the experimental test (at the loaded condition), the air temperature in the drying chamber, the relative humidity of drying chamber and solar radiation on solar collectors vary between 30 and 72 °C, 8–11% and 485–1165 W/m^2, respectively.

Results and discussion

Result of energy analysis

As shown in Figs. 1 , 2 and 3 variations of the energy utilization ratio during the experimental test of tomato,

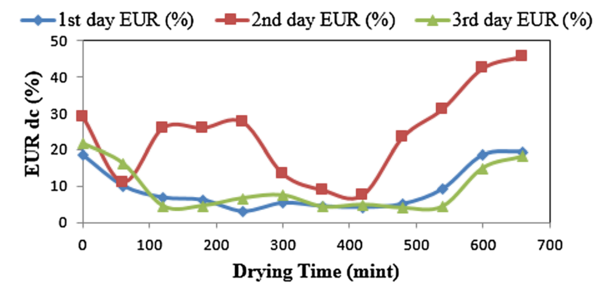

Fig. 2 Variation of energy utilization ratio in drying chamber as a function of drying time of potato

potato and onion were calculated using Eqs. (9). The analysis was conducted depending on the drying chamber flow air temperature as a function of drying time. Moreover, as drying time decreased the energy utilization ratio slightly increased with an increase in drying air temperature. The energy utilization ratio of tomato varied between 4.8 and 19.9% on the first day at drying air temperature of 45 °C, 3.4% to 26.0%, on the second day at drying air temperature of 60 °C and 3.1% to 12.9% on the third day at drying air temperature of 65 °C as shown in Fig. 1.

The energy utilization ratio of potato varied between 4.1 and 19.4% on the first day at drying air temperature of 55.9 °C, 7.4% to 45.6% on the second day at drying air temperature of 57.9 °C and 3.9 to 21.6% on the third day at drying air temperature of 55.3 °C as shown in Fig. 2.

Similarly, the energy utilization ratio of onion varied between 5.2 and 14.5% on the first day at drying air temperature of 39 °C, 6.5% to 26.6% on the second day at drying air temperature of 41.9 °C, 11.8% to 23.5% onion on the third day at drying air temperature of 61.3 °C and 8.3% to 37.4% on the fourth day at drying air temperature of 62.2 °C as shown in Fig. 3.

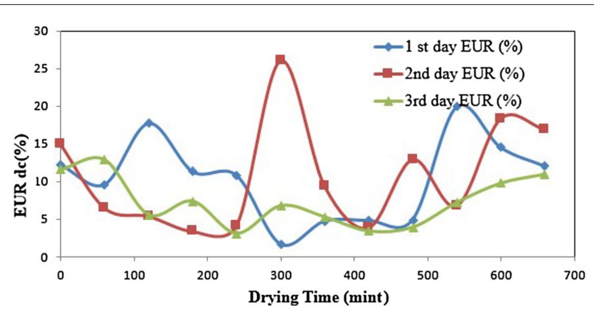

Fig. 1 Variation of energy utilization ratio in drying chamber as a function of drying time of tomato

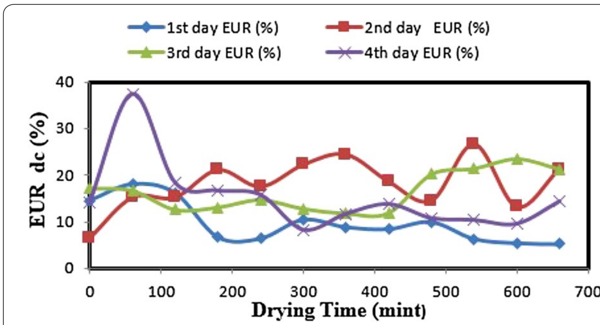

Fig. 3 Variation of energy utilization ratio in drying chamber as a function of drying time of onion

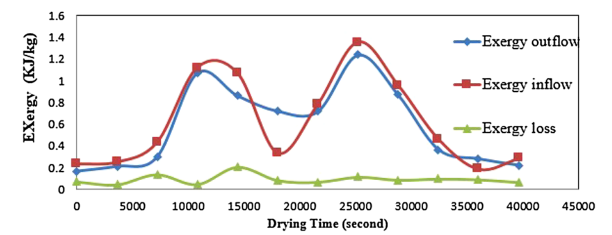

Fig. 4 Exergy as a function of drying time (1st day) tomato

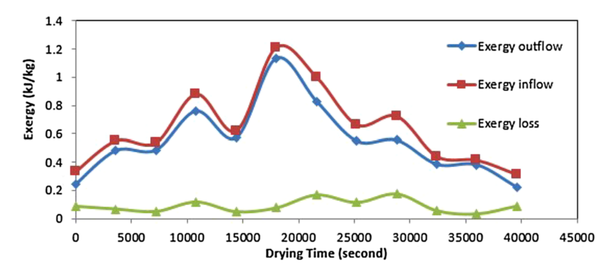

Fig. 5 Exergy as a function of drying time (2nd day) tomato

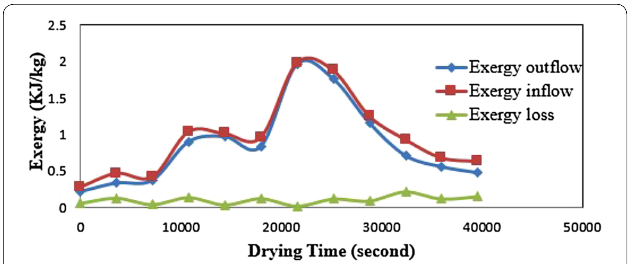

Fig. 6 Exergy as a function of time (3rd day) tomato

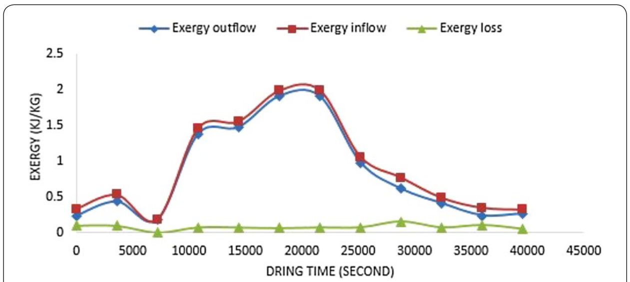

Fig. 7 Exergy as a function drying time (1st day) potato

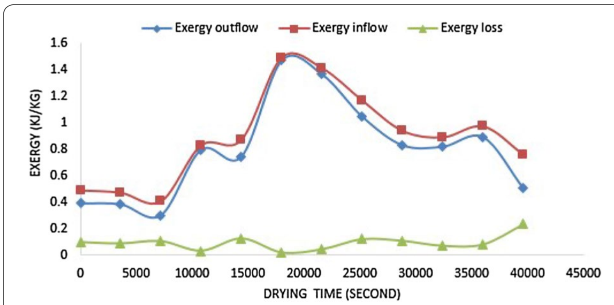

Fig. 8 Exergy as a function drying time (2nd day) potato

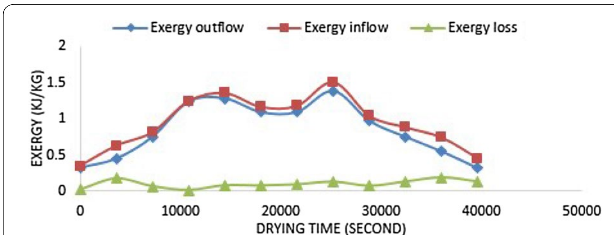

Fig. 9 Exergy as a function drying time (3rd day) potato

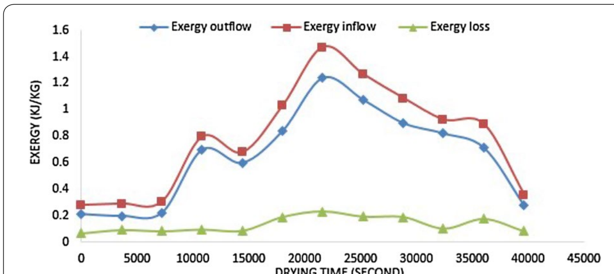

Fig. 10 Exergy as a function drying time (1st day) onion

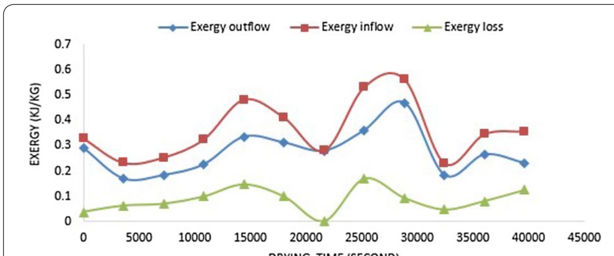

Fig. 11 Exergy as a function drying time (2nd day) onion

Result of exergy analysis

Figures 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13 illustrate the maximum and minimum values of exergy inflow, exergy outflow, and exergy losses of the drying chamber at each tray. The rate of exergy inflow as calculated from Eqs. (11) depends on the ambient and inlet air temperature of the drying chamber. The exergy inflow of the first tray was constant since the inlet temperature drying air in the drying chamber and the ambient temperature was kept constant. The exergy inflow of tomato in the drying chamber

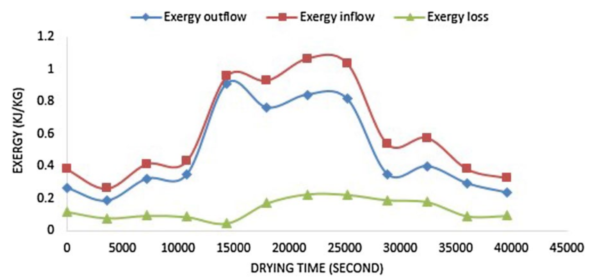

Fig. 12 Exergy as a function drying time (3rd day) onion

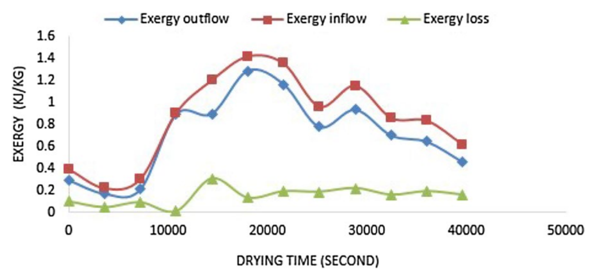

Fig. 13 Exergy as a function drying time (4th day) onion

varied between 0.188 and 1.355 kJ/kg tomato on the first day, 0.331 kJ/kg to 1.21 kJ/kg tomato on the second day and 0.28 kJ/kg to 1.981 kJ/kg tomato on the third day depending on the experimental condition of slices of tomato. The rate of exergy outflow as calculated from Eq. (12) relied on the ambient and outlet air temperature of the drying chamber. The exergy outflow of tomato in the drying chamber varied between 0.165 and 1.240 kJ/kg tomato on the first day, and 0.22 kJ/kg to 1.1134 kJ/kg tomato on the second day, and 0.221 kJ/kg to 1.960 kJ/kg tomato on the third day depending on the experimental test of tomato.

As shown in Figs. 7, 8 and 9, the exergy inflow of potato in the drying chamber varied between 0.187 and 1.987 kJ/kg potato on the first day, 0.41 kJ/kg to 1.49 kJ/kg potato on the second day, 0.35 kJ/kg to 1.511 kJ/kg potato on the third day depending on the experimental test of slices of potato. The exergy outflow of potato in the drying chamber varied between 0.181 and 1.915 kJ/kg potato on the first day, 0.303 kJ/kg to 1.470 kJ/kg potato on the second day and 0.320 kJ/kg to 1.382 kJ/kg potato on the third day depending on the experimental test of slices of potato. In addition, the exergy loss of potato in drying chamber varied between 0.06 and 0.158 kJ/kg potatoes on the first day, 0.02 kJ/kg to 0.236 kJ/kg potatoes on the second day, and 0.012 kJ/kg to 0.19 kJ/kg potatoes on the third day depending on the experimental condition of slices of potato.

Figures 10, 11, 12 and 13 illustrate that the exergy inflow of onion in the drying chamber varied between 0.277 and 1.471 kJ/kg onion on the first day, 0.231 kJ/kg to 0.562 kJ/kg onion on the second day, 0.261 kJ/kg to 1.068 kJ/kg onion on the third day and 0.22 kJ/kg to 1.416 kJ/kg on the fourth day. The exergy outflow of onion in the drying chamber varied between from 0.196 to 1.241 kJ/kg onion on the first day, 0.170 kJ/kg to 0.469 kJ/kg onion on the second day, 0.184 kJ/kg to 0.814 kJ/kg onion on the third day, and 0.172 kJ/kg to 1.283 kJ/kg on the fourth day. Besides, it depends on the experimental condition of onion. And also, the exergy loss of onion in the drying chamber varied between 0.067 kJ/kg to 0.23 kJ/kg onion on the first day, 0.001 kJ/kg to 0.170 kJ/kg onion on the second day, 0.045 kJ/kg to 0.189 kJ/kg onion on the third day, and 0.012 kJ/kg to 0.219 kJ/kg onion on the fourth day.

Figures 14, 15 and 16 show the variation of the exergy output, exergy solar radiation input and exergy efficiency, exergy utilization efficiency and exergy system efficiency in the drying chamber and flat plate solar collector as a function of drying time. The exergy efficiency for each component was calculated by using Eq. (14). It is dependent on the exergy inflow, outflow and loss of exergy in the drying chamber. As shown in Figs. 14, 15 and 16, the exergy efficiency of tomato in the drying chamber varied from 53.35 to 95.60% on the first day, 59.10% to 93.3% on the second day and 61.78% to 98.93% on the third day. It is dependent on the experimental condition of slices of tomato. The rate of exergy output was calculated using Eq. (17) and it is dependent on the ambient and outlet air temperature of the drying chamber. The exergy output of tomato in the drying chamber was found to be 80.20 W to 311.8 W on the first day, 80.9 W to 208.3 W on the second day, and 112.3 W to 182.6 W on the third day. The exergy solar radiation input was calculated by using Eq. (18) and it is dependent on the ambient temperature and the sky temperature, collector area. The exergy solar radiation of tomato varied between 166.3 w to 324.74 W on the first day, 177.44 W to 390 W on the second day

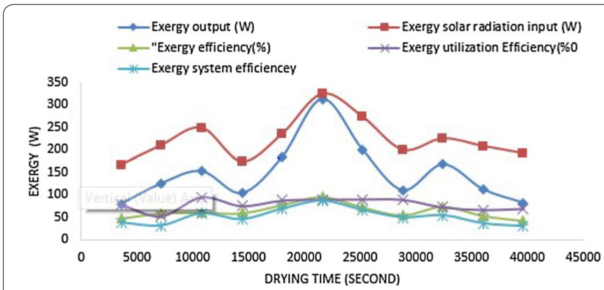

Fig. 14 Variation of efficiency as a function of drying time and exergy in the drying chamber (1st day) tomato

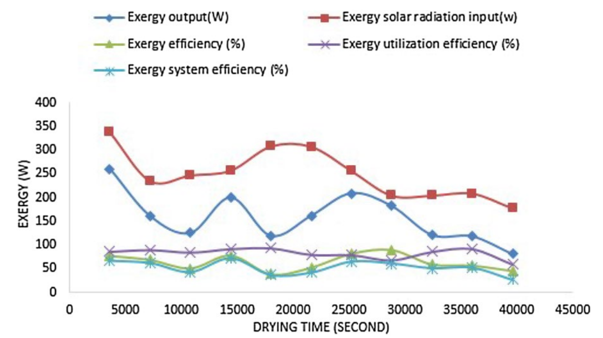

Fig. 15 Variation of efficiency as a function of drying time and exergy in the drying chamber (2nd day) tomato

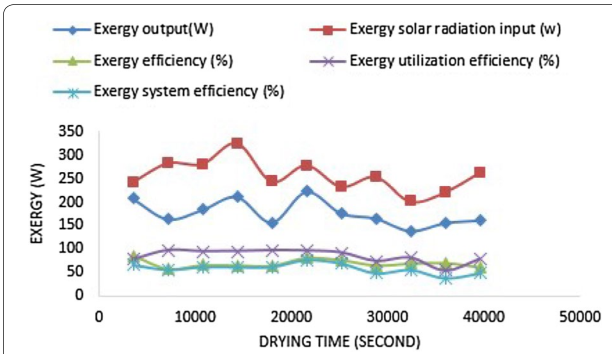

Fig. 17 Variation of efficiency as a function of drying time and exergy in the drying chamber (1st day) potato

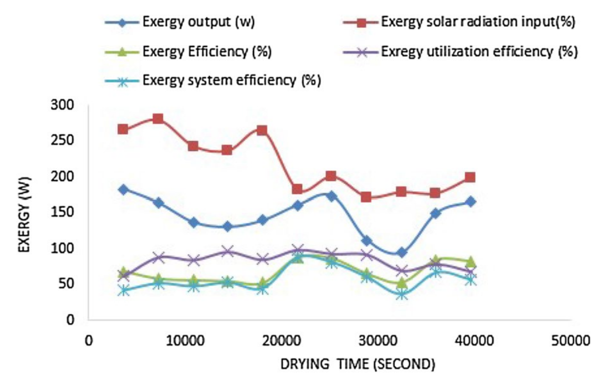

Fig. 16 Variation of efficiency as a function of drying time and exergy in the drying chamber (3rd day) tomato

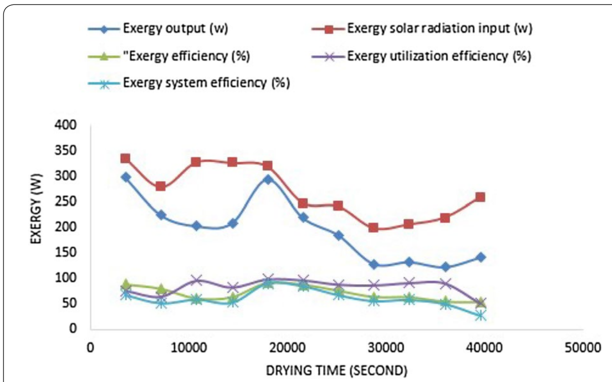

Fig. 18 Variation of efficiency as a function of drying time and exergy in the drying chamber (2nd day) potato

and 171.4 W to 387.10 W on the third day depending on the experimental test of tomato. The exergy utilization efficiency was calculated by using Eqs. (16) and it is dependent on the exergy solar radiation input and exergy output. The exergy utilization efficiency of tomato varied between from 43.2 to 95.9% on the first day, 38.7% to 89.1% on the second and 52.9% to 88.7% on the third day depending on the experimental test of tomato. The exergy system (net) efficiency was calculated by using Eq. (15). It was dependent on the exergy utilization efficiency and exergy efficiency. The exergy system (net) efficiency varied between 30.2 and 86.8% tomato on first day, 26.9% to 71.2% tomato on second day and 37.3% to 80.8% tomato on the third day depending on the experimental test of tomato.

Figures 17 and 18 illustrate the exergy efficiency of potato in the drying chamber varied from 54.17% to 96.68% on the first day, 51.1% to 98.64% on the second day and 59.1% to 97.5% on the third day depending on the experimental condition of slices of potato. The rate of exergy output was calculated using Eq. (17). It was dependent on the ambient temperature and outlet air temperature of the drying chamber. Figures 17, 18 and 19 show that the exergy output of potato in the drying chamber varied between 165.5 and 211.7 W on the first day, 122.5 W to 298.6 W on the second day, and 70.71 W to 299.3 W on the third day. The exergy solar radiation input was calculated by using Eq. (18) based on the ambient temperature, the sky temperature and the collector area. Figures 17, 18 and 19 show that the exergy solar radiation input of potato varied between 201.87 and 324.55 W on the first day, 197.9 W to 335.2 W on the second day and 129.5 W to 386.50 W on the third day depending on the experimental test of potato. The exergy utilization efficiency was calculated by using Eq. (16) and it was dependent on the exergy solar radiation input and exergy output. The exergy utilization efficiency of potato varied between 61.6 and 85.6% on the first day, 54.7% to 92.3% on the second day and 53.4% to 92.5% on the third day depending on the experimental condition of potato. The exergy system (net) efficiency was calculated by using Eq. (15) and it was dependent on the exergy utilization efficiency and exergy efficiency. Figures 17, 18 and

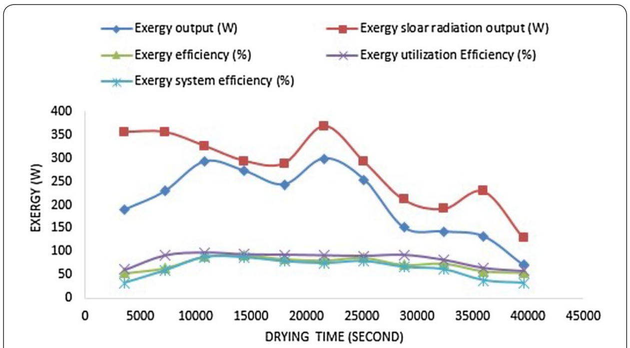

Fig. 19 Variation of efficiency as a function of drying time and exergy in the drying chamber (3rd day) potato

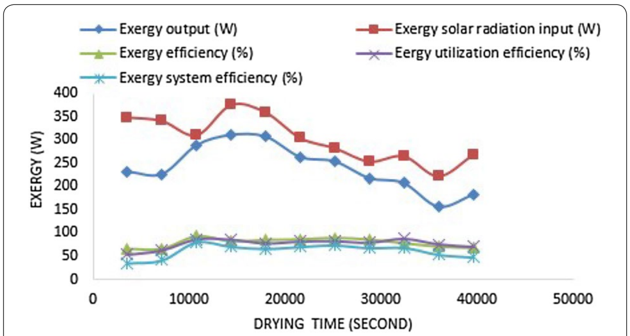

Fig. 20 Variation of efficiency as a function of drying time and exergy in the drying chamber (1st day) onion

19 show that the exergy system (net) efficiency varied between 37.9 and 76.96% on the first day, 27.9% to 91.0% on the second day and 32.3% to 87.5% on the third day depending on the experimental condition of potato.

Figures 20, 21, 22 and 23 show that the exergy efficiency of onion in the drying chamber varied between 53.06 and 87.44% on the first day and 45.45% to 96.64% on the second day, 45.84% to 96.64% on the third day and 56.6% to 98.65% on the fourth day depending on the experimental condition of onion. The rate of exergy output was calculated using Eqs. (17), and it was dependent on the ambient and outlet air temperature of the drying chamber. Figures 20, 21, 22 and 23 show that the exergy output of onion in the drying chamber varied between 156.9 and 310.3 W on the first day, 96.64 W to 133.4 W on the second day, and 126.2 W to 861.5 W on the third day and 119.0 W to 226.08 W on the fourth day depending on the experimental test of onion. The exergy solar radiation input was calculated by using Eqs. (18), based on the ambient temperature, the sky temperature, and the collector area. Figures 20, 21, 22 and 23 show that the exergy solar radiation input of onion varied between

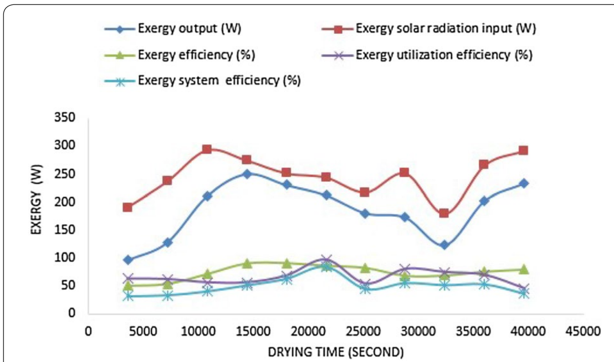

Fig. 21 Variation of efficiency as a function of drying time and exergy in the drying chamber (2nd day) onion

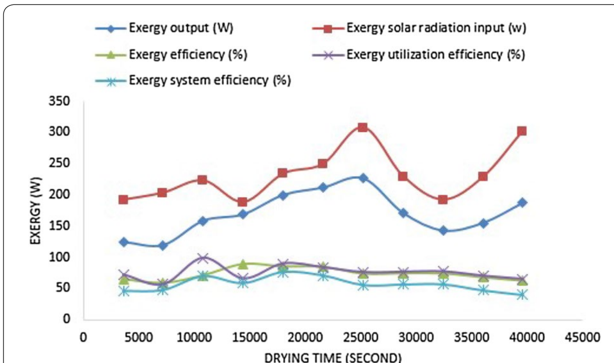

Fig. 22 Variation of efficiency as a function of drying time and exergy in the drying chamber (3rd day) onion

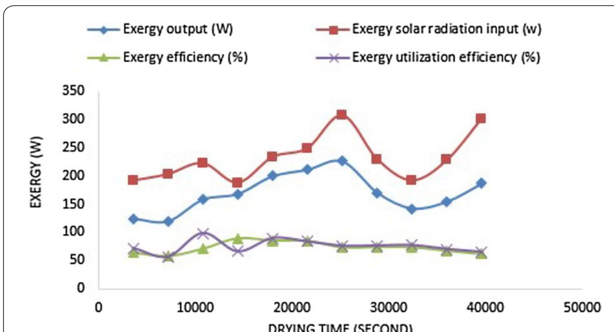

Fig. 23 Variation of efficiency as a function of drying time and exergy in the drying chamber (4th day) onion

221.5 and 310.3 W on the first day, 179.2 W to 301.8 W on the second day and 171.1 W to 1084.6 W On the third day and 188.2 W to 307.7 W on the fourth day depending on the experimental condition of potato. Figures 20, 21, 22 and 23 show the exergy utilization efficiency calculated by using Eq. (16). It was dependent on the exergy solar radiation input and exergy output. The exergy utilization efficiency of onion varied between from 66.3 to 92.9% on the first day, 50.6% to 90.09% on the second day, 56.0% to 80.1% on the third day and 58.5% to 89% on the fourth day depending on the experimental condition of onion. The exergy system (net) efficiency was calculated by using Eq. (2). It is dependent on the exergy utilization efficiency and exergy efficiency. Figures 20, 21, 22 and 23 show that the exergy system (net) efficiency varied between 35.2 and 80.1% on the first day, 31.8% to 83.8% on the second day and 32.6% to 73.1% on the third day and 40.3% to 76.6% onion the fourth day depending on the experimental condition of onion.

Conclusion

The performance of solar vegetable dryer was analyzed experimentally. The solar vegetable dryer was analyzed based on the 1st and 2nd laws of thermodynamic analysis, viz. energy and exergy analysis. In this study, tomato, potato and onion was used as to dry in the solar dryer. The air temperature required to dry the tomato is from 34.5 to 72.3 °C, for potato is from 37.5 to 66.9 °C and onion is from 36.3 to 63.4 °C. The exergy inflow in drying chamber was found to be 0.188 kJ/kg to 1.981 kJ/kg for tomato, 0.187 kJ/kg to 1.987 kJ/kg for potato, and 0.22 kJ/kg to 1.471 kJ/kg for onion. The exergy outflow in drying chamber was found to be 0.165 kJ/kg to 1.96 kJ/kg for tomato, 0.181 kJ/kg to 1.92 kJ/kg for potato and 0.17 kJ/kg to 1.283 kJ/kg for onion. The average energy utilization ratio in the drying chamber was found to be 3.1 to 26% for tomato, 3.9 to 45.6% for potato and 5.2 to 37.4% for onion. Regarding the drying period, tomato takes 33 h, potato takes 27 h and onion takes 44 h for onion during experimental test. The dried relative humidity ranges from 10.01% to 11%, for tomato, 8.22% to 10.32% for potato and 9.7% to 11.18% for onion. The energy utilization ratio in the drying chamber was found to be 3.1% to 26%, for tomato, 3.9% to 45.6% for potato and 5.2% to 37.4% for onion.

Method/experimental

Experimental set-up

The detailed information on the experimental system and instrumental set-up is given below (Bhardwaj et al. 2017). The collector part and the drying part have an area of $1 \times 2\ m^2$ and $1 \times 1.07\ m^2$, respectively. The schematic diagram of this dryer is shown in Fig. 24.

Thermocouples were used to measure ambient temperature and the drying air temperature inside the dryer chamber. The range of operational temperature is 20 °C to 150 °C.

Experimental procedure

The daily drying rate was estimated by measuring the weight loss of the product after each day of drying. The relative humidity and solar radiation data were obtained from meteorological and measuring data. All results obtained from the experiments were used to perform the energy and exergy analyses of the solar vegetable drying process. Fresh vegetable products were used in the experiments and the moisture content was recorded as 91% for tomato, 73% for potato and 81% for onion. The drying experiments were carried out at drying air temperature of 35 °C for tomato, 55 °C for potato, and 70 °C for onion and the drying air velocity was 0.5 m/s for tomato, 1.5 m/s for potato and 2 m/s for onion. The final moisture content of samples was calculated based on weight samples of the vegetables and the final drying moisture content was determined as 9%, for tomato, 12%, for potato and 13% for onion based on weight analysis. During the experiments, ambient temperature inlet and outlet temperatures of drying air in the chamber were recorded. To measure drying air temperature, thermocouple and digital thermometer with manually controlled eight (8) channels at the inlet and outlet of the drying chamber during an experimental test was used (Borah et al. 2015). The velocity of air in the drying chamber varied from 0 to 2.5 m/s which was measured from the anemometer.

Steps of drying vegetable

See Fig. 25.

Fig. 24 Experimental setup of solar dryer

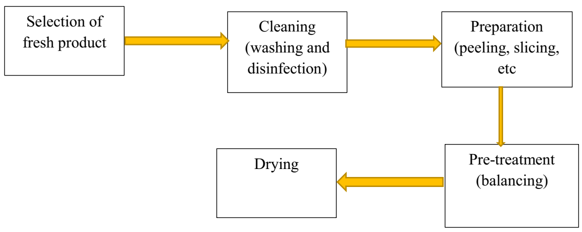

Fig. 25 Shows the flowchart of drying vegetable steps

Theoretical analysis

Analysis of solar energy

Energy analysis

The theoretical and derivation of the formulas have been based on first and second laws of thermodynamics principle to determine energy, exergy and utilization ratio of the vegetable drying system (Amjad et al. 2016). These parameters were determined at the inlet, outlet and intermediate section of the drying system based on the empirical formula and measured data on the system (i.e., solar radiation, atmospheric air temperature, drying temperature, outlet temperature, and relative humidity). The air conditioning process throughout the drying of vegetables includes the processes of heating, cooling, and humidification (Akpinar 2010). The air conditioning processes can be modeled as steady-flow processes that were analyzed by applying the steady-flow conservation of mass (for both dry air and moisture) and conservation of energy principle (El-sebaii and Shalaby 2012). General equation of mass conservation of drying air is (Minaei et al. 2014):

$$\sum \dot{m}_{ai} = \sum \dot{m}_{ao}. \tag{1}$$

General equation of mass conservation of moisture.

$$\begin{aligned} &\sum \left(\dot{m}_{wi} + \dot{m}_{mp}\right) = \sum \dot{m}_{wo} \\ &or \sum \left(\dot{m}_{ai} w_i + \dot{m}_{mp}\right) = \sum \dot{m}_{ai} w_o \end{aligned} \tag{2}$$

General equation of energy conservation.

$$\dot{Q} - \dot{W} = \sum \dot{m}_o \left(h_o + \frac{v_o^2}{2}\right) - \sum \dot{m}_i \left(h_i + \frac{v_i^2}{2}\right). \tag{3}$$

The changes in kinetic energy of fan were taken into consideration while the potential and kinetic energy in other parts of the process was neglected (Sami et al. 2011). During the energy and exergy analyses of the vegetables drying process, the following equations were generally used to compute the relative humidity and enthalpy of drying air (Arepally et al. 2017):

The relative humidity:

$$\phi = \frac{wp}{(0.622 + w) p_{\mathrm{sat@T}}}, \tag{4}$$

where w is the specific humidity, p atmospheric pressure, $p_{\mathrm{sat@T}}$ the saturated vapor pressure of drying air.

The enthalpy of drying air:

$$h = C_{pda} T + w h_{\mathrm{sat@T}}, \tag{5}$$

where C_{pda} the specific heat of drying air, T is drying air temperature, and $h_{\mathrm{sat@T}}$ is the enthalpy of saturated vapor.

Determination of fan outlet conditions

$$h_{fo} = \left[\left(\dot{w}_f - \frac{v_{fo}^2}{2 \times 1000}\right)\left(\frac{1}{\dot{m}_{da}}\right)\right] + h_{fi}, \tag{6}$$

where h_{fi} characterizes the enthalpy of drying air at the inlet of the fan, h_{fo} the enthalpy at the outlet of the fan v_{fo} the drying air velocity at the outlet of the fan, $\dot{w}_f$ fan energy and $\dot{m}_{da}$ mass flow of drying air (R. Development. 2016). Considering the values of dry-bulb temperature and enthalpy from Eq. (4), the specific and relative humidity of drying air at the fan were determined by using the psychrometric chart (I. S. U. N. Drying 2006).

Determination of the outlet conditions of the tray

The inlet conditions of the drying chamber were determined depending on the inlet temperatures and specific humidity of drying air (Bolaji and Olalusi 2008). The inlet conditions of the tray were assumed as equal to the inlet conditions of the drying chamber (Celma and Cuadros 2009). Meanwhile, it was considered that the mass flow rate of drying air was equally passed throughout the tray (Kalaiarasi et al. 2016). Thus, the inlet conditions of the tray can be written:

$$w_{\mathrm{di}} = w_{\mathrm{tri}}, T_{\mathrm{dci}} = T_{\mathrm{tri}},$$
$$\phi_{\mathrm{dci}} = \phi_{\mathrm{tri}}, h_{\mathrm{dci}} = h_{\mathrm{tri}} \text{ and } \dot{m}_{da} = \dot{m}_{\mathrm{datri}}.$$

Using Eqs. (1) and (2), the equation of the specific humidity at the outlet of the tray was derived:

$$w_{\mathrm{tro}} = w_{\mathrm{tri}} + \frac{\dot{m}_{\mathrm{vegetable}}}{\dot{m}_{da}}, \tag{7}$$

where w_{tri} is the specific humidity at the inlet of the tray, $\dot{m}_{\mathrm{vegetable}}$ the mass flow rate of the moisture removed from the vegetable (product). The relative humidity and enthalpy of drying air at the outlet of the tray were, respectively, estimated using Eqs. (4 and 5) (Singh and Kumar 2012). During the humidification process at the tray, the heat transfer can be calculated using the following equations:

$$\dot{Q}_{tr} = \dot{m}_{da}\left(h_{\mathrm{tri@T}} - h_{\mathrm{tro@T}}\right), \tag{8}$$

where $h_{\mathrm{tri@T}}$, $h_{\mathrm{tro@T}}$ are the enthalpies at the inlet and outlet of the tray.

During the experiments, ambient temperature and the relative humidity, inlet and outlet temperature of drying air in the dryer chamber were recorded as shown in Fig. 7 (Arepally et al. 2017) (Fig. 26).

The inlet conditions of the tray were assumed as equal to the inlet conditions of the dry drying chamber (George 2007). In addition, the outlet conditions of trays were assumed as equal to the outlet conditions of the drying chamber (Darvishi et al. 2018). Solar dryer energy analysis based on the first law of thermodynamics never reflects the quality of energy destruction (Bennamoun 2012). During the solar drying process, the energy utilization ratio of the drying chamber is estimated using the following equation (Minaei et al. 2014; Akpinar et al. 2006):

$$EUR = \frac{\dot{m}_{ia}(h_{ia} - h_{oa})}{\dot{m}_{ia}C(T_{ia} - T_{aai})} = \frac{cp_i T_{dci} - cp_0 T_{dco}}{cp_i T_{dci} - cp_o T_a}, \tag{9}$$

where $\dot{m}_{ia}$ is the mass flow rate of the dry air (kg/s), h_{oa} is absolute humidity of the air leaving the drying chamber (%), h_{ia} is the absolute humidity of the air entering the drying chamber (%), c = specific heat of air (J/kg/°C), and EUR, the energy utilization ratio.

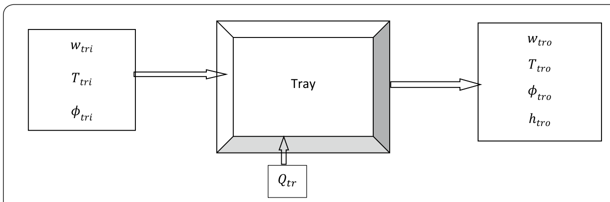

Fig. 26 Schematic illustration of the tray

Exergy analysis

Exergy is the maximum amount of work that can be produced by the system or flow of mater or energy reach equilibrium with a reference environment. Energy and exergy analyses of the drying process should be performed to determine the energy interaction and thermodynamics behavior of drying air throughout a drying chamber (Fudholi et al. 2014a). Exergy analysis allows for effective energy resource use because the analysis enables the determination of locations and magnitudes of the losses (Fudholi et al. 2014b).

Exergy analysis is based on the second of law of thermodynamics therefore, the general form of the exergy equation that is applicable to steady-flow systems may be expressed as (Niksiar and Rahimi 2009; Oztop et al. 2013) (Fig. 27):

$$\mathrm{Ex} = \dot{m}cp\left[(T - T_a) - T_a \ln\frac{T}{T_a}\right], \tag{10}$$

where Ex is the exergy, $\dot{m}$ the mass flow rate (kg/s), and T_a the ambient temperature (°C).

For the exergy inflow to the drying chamber

$$\mathrm{Ex}_{\mathrm{dci}} = \dot{m}cp\left[(T_{\mathrm{dci}} - T_a) - T_a \ln\frac{T_{\mathrm{dci}}}{T_a}\right], \tag{11}$$

where T_{dci} is the inflow temperature of the drying chamber.

For the exergy outflow from the drying chamber:

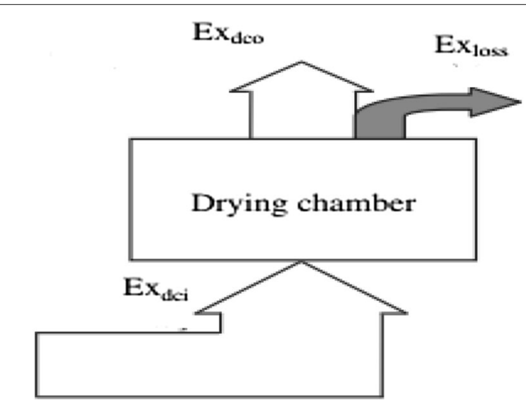

Fig. 27 Exergy balance (Niksiar and Rahimi 2009)

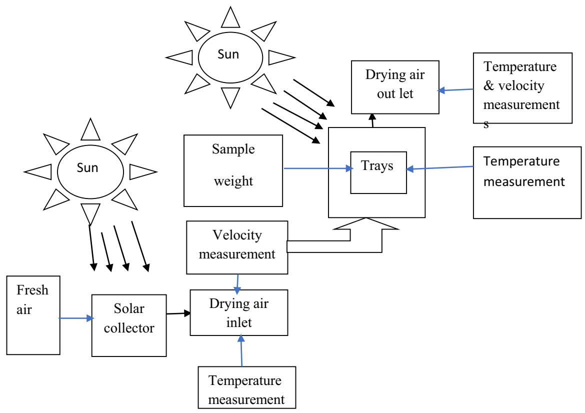

Fig. 28 Flowchart of the solar drying process

$$\mathrm{Ex_{dco}} = \dot{m}\mathrm{cp}\left[(T_{\mathrm{dco}} - T_a) - T_a \ln\frac{T_{\mathrm{dco}}}{T_a}\right]. \quad (12)$$

Exergy loss during solar drying is determined by

$$\mathrm{Ex_{loss}} = \mathrm{Ex_{dci}} - \mathrm{Ex_{dco}}. \quad (13)$$

Exergy efficiency can be defined as the ratio of (No Title. 2004) energy use (investment) in product drying to the exergy of the drying air supplied to the system (No Title. 2004). However, this efficiency can also be defined as the ratio of exergy outflow to exergy inflow in the drying chamber. The exergy efficiencies of the drying chamber can be determined based on this definition (Zohri et al. 2018). Therefore, the general form of exergy efficiency is expressed as follows (Fudholi et al. 2014a):

$$\eta_{\mathrm{Ex.do}} = \frac{\mathrm{Ex_{dco}}}{\mathrm{Ex_{dci}}} = 1 - \frac{\mathrm{Ex_{loss}}}{\mathrm{Ex_{dci}}}. \quad (14)$$

Given a greenhouse tunnel-type solar dryer system with a chimney that uses solar radiation energy, the given system efficiency is (Bolaji and Olalusi 2008):

$$\eta_{\mathrm{Ex.net}} = \eta_{\mathrm{Ex.da}} \times \eta_{\mathrm{ex.solar}}. \quad (15)$$

For a greenhouse solar dryer system, the exergy utilization efficiency ($\eta_{\mathrm{ex.solar}}$) required to raise internal air temperature is determined as follows (Prommas et al. 2010):

$$\eta_{\mathrm{Ex.solar}} = \frac{\mathrm{Ex_{out}}}{\mathrm{Ex_{rad}}}, \quad (16)$$

where the exergy output ($\mathrm{Ex_{out}}$) and the exergy of solar radiation input ($\mathrm{Ex_{rad}}$) to the dryer was calculated as follows:

$$\mathrm{Ex_{out}} = \left(1 - \frac{T_a}{T_{at}}\right)\left[\frac{\dot{m}c(T_{at} - T_a)}{\Delta t}\right], \quad (17)$$

where T_{at} is the air temperature in the dryer (°C) and T_a is the ambient temperature (°C).

$$\mathrm{Ex_{rad}} = \mathrm{SXA}\left[1 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4\right], \quad (18)$$

where T_s is the sky temperature.

The exergy efficiency of a system or process is maximized when exergy loss ($\mathrm{Ex_{loss}}$) is minimized.

Experimental analysis of solar vegetable dryer

Solar collectors as heat exchangers transfer the absorbed solar radiation to air passing next to the absorber plate (Akpinar 2010). Thus, hot air is obtained from these collectors and they are used in space heating, agricultural product drying, greenhouse heating and preheating in ventilation systems (Tripathy and Kumar 2009).

Solar air collector is a simple device for air heating by utilizing solar energy for many applications, which require low-to-moderate temperature below 60 °C such as drying and space heating (Arepally et al. 2017; Bennamoun 2012).

The flowchart of the drying process during the experiment is shown in Fig. 28.

Abbreviations

A_c: Collector area (m^2); D_R: Drying rate (%); EUR: Energy utilization ratio (%); E_x: Exergy (w); Ex_{dci}: Exergy inflow to the drying chamber (KJ/kg); Ex_{dco}: Exergy outflow from the drying chamber (KJ/kg); Ex_{loss}: Exergy loss (kJ/kg); Ex_{out}: Exergy out (w); Ex_{rad}: Exergy of solar radiation input (w); T: Drying air temperature (°C); T_a: Ambient temperature (°C); T_o: Outlet air temperature (°C); T_i: Inlet air temperature (°C); T_{dci}: Drying air temperature inlet of drying chamber (°C);

T_{dco}: Drying air temperature outlet of drying chamber (°C); T_s: Sky temperature (°C); t_{os}: Time consumed (s); t_{sd}: Time consumed by solar dryer (s); W: Specific humidity; w_{di}: Specific humidity of inlet of drying chamber; w_{do}: Specific humidity outlet of drying chamber; w_{tri}: Specific humidity inlet of the tray; w_{tro}: Specific humidity outlet of the tray; W: Mass of water removed (kg/s); x_{2m}: Dryer outlet absolute humidity; x_a: Ambient absolute humidity (%); ϕ: Relative humidity (%); ϕ_{dci}: Relative humidity inlet of drying chamber (%); ϕ_{dco}: Relative humidity outlet of drying chamber (%); η_C: Collection efficiency (%); η_S: System drying efficiency (%); η_d: Drying efficiency (%); $\eta_{Ex.do}$: Exergy efficiency (%); $\eta_{Ex.nt}$: System efficiency (%); $\eta_{Ex.solar}$: Utilization efficiency (%).

Acknowledgements
The authors would like to thank University of Gondar for its support for the achievement of the objective of the research and Fogera woreda agricultural office allowing us to collect the data which was used as input for the research output.

Authors' contributions
YTS: Conception and design, experimental and performance analysis solar dryer of the system and interpretation of data, Drafting the article, Critical revision of the article, final approval of the version of the manuscript. GTA: Conception and design, experimental and performance analysis solar dryer of the system and interpretation of data, Drafting the article, Critical revision of the article, final approval of the version of the manuscript. Both authors read and approved the final manuscript.

Funding
The research was supported by a grant from University of Gondar, Institute of Technology. The granting agency did not have a role in the design; Collection, analysis, and interpretation of data, or in writing the manuscript.

Availability of data and materials
When ethics statement was obtained from the Fogera woreda agricultural office, we have agreed and signed not to publish the raw data retrieved from information of the mothers. However, the data sets collected and analyzed for the current study are available from the corresponding author and can be obtained on a reasonable request

Ethics approval and consent to participate
Ethical clearance was obtained from Ethical review committee of university of Gondar Department of Mechanical Engineering and letter of permission was obtained from Fogera woreda agricultural office. Then, participants were informed about the purpose of the study, the importance of their participation and their right to withdraw at any time. Informed consent was obtained prior to data collection. Confidentiality of the information was maintained and no identifying information was collected from participants.

Competing interests
The authors declare no competing interests.

Author details
[1] Department of Mechanical Engineering, Institute of Technology, University of Gondar, P.O. Box 196, Gondar, Ethiopia. [2] Department of Electrical and Computer Engineering, Institute of Technology, University of Gondar, P.O. Box 196, Gondar, Ethiopia.

Appendix

Appendix A

See Table 1.

Table 1 Shows production and usable product in Woreta

Year	Onion production (k ton)	Usable onion (k ton)	Production tomato (k ton)	Usable tomato (k ton)	Production Potato (k ton)	Usable potato (k ton)
1905	480	240	8.04	3.7788	16.68	5.38764
1906	4462.5	2231.25	39.558	18.59226	18.48	5.96904
1907	5412	2706	110.51	51.937	42.076	13.590548
1908	7517.4	3758.7	256.9077	12.074619	90.150	291.1845
1909	15210.	7605	457.716	215.12652	131.148	42.360804
2010	13527.54	6763.77	520.305	244.54335	106.4664	34.3886472
2011	82624.5	41312.25	275.135	129.31345	128.199	41.408277
2012	82282.2	41,141.1	632.89	297.4583	468.269	151.250887
2013	77,927.1	38,963.55	1358.891	638.67877	361.416	116.737368
2014	10,728.99	53,644.950	1226.624	576.51328	520.714	168.190622
2015	112,920.6	56,460.300	1337.643	628.69221	540.262	174.504626
2016	151,515	75,757.500	1604.556	754.14132	27.5625	8.9026875
2017	366,131.25	183,065.625	2,167,880	1018.9036	1228.625	39.6845875
2018	345.5325	172.76625	1.151775	0.54133425	1.977	0.638571

Appendix B

See Table 2.

Table 2 Shows recording mean temperature, radiation and drying humidity of Woreta for selected day in the month

No.	Month	Time of recording (temperature in °C)								Date
		3:00	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	
1	March	19	20	28	31	29	29	31	29	16/03/2016
2	≫	20	22	30	32	31	31	30.8	30	18/03/2016
3	≫	19	21.8	27.8	29	32	31.8	30.3	30	20/03/2016
4	≫	19	22	28	40	41	33.5	34.3	32.9	22/03/2016
5	≫	20	24	29.8	38.9	40	37.3	37	34.3	28/03/2016
6	≫	17	23.8	29	34.5	37.5	36.7	33.8	32	31/03/2016
No.	**Month**	**Time recording (horizontal radiation in W/m^2)**								**Date**
		3:00	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	
1	March	589	679	923	1075	1145	1105	1065	933	16/03/2016
2	≫	584	681	923	1070	1137	1103	1053	927	18/03/2016
3	≫	558	668	913	975	1035	1053	1013	922	20/03/2016
4	≫	547	558	798	1205	1107	1015	989	763	22/03/2016
5	≫	543	687	914	953	999	1102	1087	921	28/03/2016
6	≫	568	698	912	973	997	1026	1031	957	31/03/2016
No.	**Month**	**Time recording (dry humidity in %)**								**Date**
		3:00	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	
1	March	36	35.3	31	29	29.3	31	31.5	32	16/03/2016
2	≫	31	30.7	29	28.3	28.1	27.4	28	27	18/03/2016
3	≫	30	29.5	23.5	22.3	21.8	19.5	21.8	22	20/03/2016
4	≫	23	21	20.8	18	17.8	17	21	21.8	22/03/2016
5	≫	24.1	24	23	13.5	14.5	14.5	17.5	18	28/03/2016
6	≫	23.2	22.8	22.1	14.5	14	14.1	18.3	18.5	31/03/2016
No.	**Month**	**Time recording (temperature in °C)**								**Date**
	April	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	
1	≫	23.4	31.1	33.2	34.8	35.9	35.9	33.3	31.3	8/04/2016
2	≫	23.4	25.1	32	32.3	31.8	33.8	29.9	30.1	11/04/2016
3	≫	22.3	24.8	31.2	32.1	32.8	33.1	30.9	29.5	16/04/2016
4	≫	25.4	28.9	32.3	33.5	32.3	31.9	31.1	29.9	20/04/2016
5	≫	25	30.1	38.2	38.8	37.3	34.3	33.9	32.9	25/04/2016
6	≫	27.6	29.4	32.8	33.8	34.9	33.9	34.5	34.6	27/04/2016
No.	**Month**	**Time recording (horizontal radiation in W/m^2)**								**Date**
	April	**3:00**	**4:00**	**5:00**	**6:00**	**7:00**	**8:00**	**9:00**	**10:00**	
1	≫	863	1120	1165	1175	1107	1062	873	765	8/04/2016
2	≫	793	923	1001	1056	1108	990	866	792	11/04/2016
3	≫	798	993	1023	1078	1124	1095	998	812	16/04/2016
4	≫	509	943	1021	1107	1074	1030	894	794	20/04/2016
5	≫	659	822	1004	1106	1098	1023	998	621	25/04/2016
6	≫	579	820	931	1045	1105	1062	1014	943	27/04/2016

Table 2 (continued)

No.	Month	Time recording (dry humidity in %)								Date
	April	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	
1	≫	18.5	17.5	16.5	16.3	17.9	12.9	12.3	13.3	8/04/2016
2		23.1	22.9	24	26.5	31.8	31.1	28	39.1	11/04/2016
3		22.3	23.8	25.1	24.3	27.9	28.4	30.1	34.7	16/04/2016
4		32.6	23.5	19.1	17.6	18.9	19.8	20.1	21.3	20/04/2016
5		30.1	23.6	24.3	21.7	22.7	23.2	24.8	25.5	25/04/2016
6		43.9	38.4	33.3	31.8	29.3	31.3	32.8	33.2	27/04/2016

Appendix C

Tables 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 show the result of exergy analysis.

Table 3 Result of exergy analysis day 1 (tomato)

Time (s)	Ex_{dco}(kJ/kg)	Ex_{dci}(kJ/kg)	Ex_{loss}(kJ/kg)	Ex_{out} (w)	Ex_{rad} (w)	$\eta_{Ex.solar}$ (%)	$\eta_{Ex.do}$(%)	$\eta_{Ex.net}$ (%)	T_a (°C)	T_{dco} (°C)	T_{dci} (°C)	$\bar{c}_p$(kJ/kg)	
0	0.165	0.237	0.072	–	234.74	–	56.4	–	24.5	34.5	36.1	1.0052	1.0052
3600	0.210	0.254	0.044	80.2	166.30	48.2	79.05	38.1	27.5	38.8	40	1.0054	1.0054
7200	0.296	0.434	0.138	125.4	209.80	59.7	53.35	31,8	27.6	41.1	44	1.0054	1.0055
10,800	1.073	1.120	0.047	152.7	248.80	61.4	95.6	58.7	30.1	53.8	56.8	1.0059	1.0060
14,400	0.864	1.071	0.207	104.2	173.40	60.1	76.04	45.7	30.2	53.6	56.4	1.0059	1.0060
18,000	0.720	0.336	0.084	183.3	234.74	78.1	88.30	68.9	30.1	49.8	50.1	1.0057	1.0058
21,600	0.717	0.785	0.068	311.8	324.80	95.9	90.52	86.8	28	49.2	50.2	1.0057	1.0057
25,200	1.240	1.355	0.115	200.1	273.67	73.1	90.72	66.3	28.7	56.8	58.2	1.0059	1.0060
28,800	0.870	0.957	0.087	110.5	199.5	55.4	90.00	49.8	28.8	52.2	53.4	1.0058	1.0058
32,400	0.365	0.463	0.098	167.8	224.8	74.6	73.13	54.5	27.1	42.1	45.8	1.0055	1.0056
36,000	0.279	0.188	0.091	112.4	207.7	54.1	67.40	36.5	27	40.1	42.3	1.0054	1.0055
39,600	0.220	0.286	0.066	82.68	191.77	43.2	70.00	30.2	26.8	38.4	40.1	1.0053	1.0054

Table 4 Result of exergy analysis 2nd day (tomato)

Time (s)	Ex_{dco} (KJ/kg)	Ex_{dci} (KJ/kg)	Ex_{loss} (kJ/kg)	Ex_{out} (w)	Ex_{rad} (w)	$\eta_{Ex.solar}$ (%)	$\eta_{Ex.do}$ (%)	$\eta_{Ex.net}$ (%)	T_a (°C)	T_{dco} (°C)	T_{dci} (C)	$\bar{c}_p$ (KJ/kg. K)	
0	0.243	0.331	0.088	–	390.00	–	63.78	–	22.1	34.2	36.3	1.0051	1.0051
3600	0.481	0.549	0.068	260.1	337.96	76.9	85.86	66.0	24.6	41.8	43	1.0054	1.0054
7200	0.485	0.535	0.05	160.9	234.97	68.5	89.69	61.4	29.5	46.9	47.8	1.0057	1.0057
10,800	0.759	0.878	0.119	125.6	246.99	51.0	84.32	43.0	30.3	52.1	53.8	1.0058	1.0059
14,400	0.571	0.619	0.048	199.8	257.12	77.7	91.59	71.2	29.1	48	48.8	1.0057	1.0059
18,000	1.134	1.210	0.076	119.3	308.14	38.7	93.30	36.9	30.1	57	66.3	1.0060	1.0063
21,600	0.829	0.999	0.17	161.8	307.34	52.6	79.49	41.8	30.9	53.1	55.3	1.0059	1.0060
25,200	0.547	0.662	0.115	208.9	256.22	81.5	78.98	64.4	29.5	48	49.9	1.0057	1.0058
28,800	0.554	0.722	0.177	181.9	204.23	89.1	68.05	60.6	28.5	47.1	49.8	1.0056	1.0057
32,400	0.383	0.438	0.055	121.2	204.40	59.3	85.64	50.8	28.4	43.8	44.9	1.0055	1.0056
36,000	0.380	0.412	0.032	118.4	208.60	56.7	91.58	51.9	28.1	41.2	44.1	1.0055	1.0055
39,600	0.220	0.310	0.09	80.95	177.44	45.6	59.10	26.9	27.5	39.1	41.4	1.0054	1.0055

Table 5 Result of exergy analysis 3rd day (tomato)

Time (s)	Ex_{dco} (kJ/kg)	Ex_{dci} (J/kg)	Ex_{loss} (kJ/kg)	Ex_{out} (w)	Ex_{rad} (w)	$\eta_{Ex.solar}$ (%)	$\eta_{Ex.do}$ (%)	$\eta_{Ex.net}$ (%)	T_a (°C)	T_{dco} (°C)	T_{dci} (°C)	$\bar{c}_p$ (KJ/kg. K)	
0	0.221	0.280	0.059	–	387.1	–	73.30	–	21.3	32.8	34.5	1.005	1.005
3600	0.340	0.470	0.130	182.6	265.7	68.72	61.76	42.4	24.1	38.9	41.1	1.0053	1.0053
7200	0.378	0.421	0.043	163.7	279.5	58.6	88.62	51.9	27.6	42.9	43.8	1.0055	1.0055
10,800	0.903	1.040	0.138	137.1	242.7	56.5	84.72	47.8	32.2	56.2	58.1	1.006	1.0061
14,400	0.974	1.012	0.038	130.6	236.5	55.2	96.10	53.0	33.1	58.1	58.9	1.0061	1.0061
18,000	0.838	0.962	0.124	139.7	263.9	52.9	85.20	45.1	32	55.1	56.8	1.0060	1.0060
21,600	1.960	1.981	0.021	160.9	181.5	88.7	96.93	87.74	36.1	72.1	72.3	1.0066	1.0066
25,200	1.762	1.880	0.118	173.2	200.0	86.6	93.30	80.8	34.8	68.8	70	1.0065	1.0065
28,800	1.162	1.253	0.091	112.3	171.4	65.5	92.17	60.4	31.8	59.1	60.2	1.0061	1.0061
32,400	0.714	0.931	0.217	95.41	178.1	53.6	69.61	37.3	29.6	50.8	53.9	1.0058	1.0059
36,000	0.561	0.680	0.119	150.3	176.5	85.1	78.79	67.1	28.5	47.2	49.2	1.0056	1.0057
39,600	0.480	0.632	0.152	165.3	199.1	83.0	68.33	56.7	27.1	44.3	47.1	1.0055	1.0056

Table 6 Result of exergy analysis (potato) 1st day

Time (s)	Ex_{dco} (kJ/kg)	Ex_{dci} (KJ/kg)	Ex_{loss} (KJ/kg)	Ex_{out} (w)	Ex_{rad} (w)	$\eta_{Ex.solar}$ (%)	$\eta_{Ex.do}$ (%)	$\eta_{Ex.net}$ (%)	T_a (°C)	T_{dco} (°C)	T_{dci} (°C)	$\bar{c}_p$ (KJ/kg. K)	
0	0.230	0.330	0.10	–	323.20	–	56.52	–	23.6	35.3	37.9	1.0051	1.0052
3600	0.434	0.531	0.097	207.7	242.66	85.6	77.65	66.5	27.7	44.1	45.9	1.0055	1.0056
7200	0.181	0.187	0.006	164.1	282.34	58.1	96.68	56.2	28.5	49.3	50.8	1.0057	1.0058
10,800	1.381	1.457	0.076	184.1	280.70	65.6	94.49	62.0	28.7	58.4	60.3	1.006	1.0061
14,400	1.479	1.554	0.075	211.7	324.55	65.2	94.93	61.9	29.3	60.1	61.0	1.0061	1.0061
18,000	1.915	1.982	0.067	156.8	243.30	64.4	96.50	62.1	32.1	62.8	64.5	1.0062	1.00625
21,600	1.910	1.987	0.077	222.9	278.10	80.2	95.97	76.9	30.1	65.3	66.9	1.0062	1.0063
25,200	0.981	1.060	0.079	176.7	232.64	75.9	91.89	69.7	30.0	55.9	57.0	1.006	1.00602
28,800	0.613	0.771	0.158	165.5	253.40	65.3	74.23	48.5	29.5	49.1	50.1	1.0057	1.0058
32,400	0.410	0.488	0.078	138.8	201.87	68.8	80.97	55.7	28.6	44.5	46.1	1.0056	1.0056
36,000	0.240	0.350	0.11	155.8	221.4	70.1	54.17	37.9	26.3	38.4	42.1	1.0053	1.0054
39,600	0.266	0.324	0.058	161.5	262.1	61.6	78.19	48.2	24.2	34.2	38.3	1.0051	1.0053

Table 7 Result of exergy analysis (potato) 2nd day

Time (s)	Ex_{dco} (KJ/kg)	Ex_{dci}(kJ/kg)	Ex_{loss} (kJ/kg)	Ex_{out} (w)	Ex_{rad} (w)	$\eta_{Ex.solar}$ (%)	$\eta_{Ex.do}$ (%)	$\eta_{Ex.net}$ (%)	T_a (°C)	T_{dco} (°C)	T_{dci} (°C)	$\bar{c}_p$ (kJ/kg K)	
0	0.392	0.492	0.10	–	304.0	–	74.48	–	22.9	36.2	40.3	1.0051	1.0053
3600	0.385	0.475	0.09	298.6	335.2	89.1	76.63	68.3	23.1	38.4	41.8	1.0052	1.0053
7200	0.303	0.410	0.107	224.8	278.6	80.7	64.68	52.2	25.5	39.1	42.5	1.0053	1.0054
10,800	0.797	0.831	0.034	203.2	327.7	62.0	95.93	59.5	27.3	48.1	50.2	1.0056	1.0057
14,400	0.745	0.873	0.128	208.8	326.1	64.3	82.82	53.3	27.7	49.3	51.2	1.0057	1.0057
18,000	1.470	1.490	0.02	294.9	319.4	92.3	98.64	91.0	28.1	54.5	58.2	1.0058	1.0059
21,600	1.365	1.410	0.045	219.5	247.6	88.6	96.70	85.7	30.9	58.2	61.1	1.0061	1.0061
25,200	1.045	1.167	0.122	185.3	240.7	77.0	88.33	68.0	30.5	56.3	57.9	1.0060	1.0061
28,800	0.830	0.939	0.109	128.6	197.9	64.9	86.87	56.4	30.3	53.2	54.8	1.0059	1.0059
32,400	0.820	0.891	0.071	132.5	205.7	64.4	91.34	58.8	28.1	50.8	51.8	1.0057	1.0060
36,000	0.891	0.973	0.082	122.5	219.2	55.8	90.79	50.7	26.2	45.3	47.3	1.0055	1.0056
39,600	0.504	0.760	0.236	141.6	258.9	54.7	51.1	27.9	24.5	42.1	46.3	1.0054	1.0055

Table 8 Result of exergy analysis (potato) 3rd day

Time (s)	Ex_{dco} (kJ/kg)	Ex_{dci} (KJ/kg)	Ex_{loss} (kJ/kg)	Ex_{out} (w)	Ex_{rad} (w)	$\eta_{Ex.solar}$ (%)	$\eta_{Ex.do}$ (%)	$\eta_{Ex.net}$	T_a (°C)	T_{dco} (°C)	T_{dci} (°C)	$\bar{c}_p$ (kJ/kg K)	
0	0.331	0.350	0.019	–	386.5	–	94.25	–	22.5	34.3	37.5	1.005	1.0052
3600	0.455	0.631	0.176	190.3	356.2	53.4	61.34	32.7	24.1	40.8	44.0	1.0053	1.0054
7200	0.753	0.817	0.064	229.1	356.2	64.3	91.46	58.8	24.5	46.1	47.1	1.0055	1.0055
10,800	1.236	1.248	0.012	292.8	326.3	89.7	97.50	87.5	27.5	55.5	56.8	1.0058	1.0059
14,400	1.280	1.359	0.079	272.3	294.3	92.5	93.83	86.8	29.5	58.1	60.1	1.0060	1.0061
18,000	1.091	1.166	0.075	243.5	289.3	84.2	93.12	78.4	28.5	54.8	56.9	1.0059	1.0059
21,600	1.093	1.183	0.091	299.3	368.6	81.2	91.69	74.5	27.8	54.1	55.2	1.0058	1.0059
25,200	1.382	1.511	0.129	254.1	292.5	86.9	90.63	78.8	28.4	58.1	59.6	1.006	1.006
28,800	0.970	1.041	0.071	151.4	211.8	71.5	92.68	66.3	29.5	54.3	55.3	1.0059	1.0059
32,400	0.751	0.883	0.132	143.1	191.9	74.5	82.42	61.4	28.8	54.2	55.1	1.0058	1.0059
36,000	0.551	0.741	0.190	132.7	229.5	57.8	65.52	37.9	26.3	44.7	47.9	1.0055	1.0056
39,600	0.320	0.451	0.131	70.71	129.5	54.6	59.10	32.3	24.5	38.3	41.2	1.0052	1.0057

Table 9 Result of exergy analysis [onion] 1st day

Time (s)	Ex_{dco}(KJ/kg)	Ex_{dci}(KJ/kg)	Ex_{loss}(KJ/kg)	Ex_{out} (w)	Ex_{rad} (w)	$\eta_{Ex.solar}$ %	$\eta_{Ex.do}$(%)	$\eta_{Ex.net}$(%)	T_a (°C)	T_{dco} (°C)	T_{dci} (°C)	$\bar{c}_p$ (KJ/kg K)	
0	0.210	0.277	0.067	–	307.0	–	68.10	–	23.5	34.5	36.3	1.0051	1.0052
3600	0.196	0.288	0.092	231.5	349.2	66.3	53.06	35.2	24.8	35.7	38.1	1.0052	1.0053
7200	0.221	0.304	0.083	226.4	341.3	66.4	62.44	41.5	25.8	37.3	39.5	1.0053	1.0053
10,800	0.698	0.794	0.096	288.3	310.4	92.9	86.25	80.1	27.9	48.8	50.3	1.0057	1.0057
14,400	0.598	0.676	0.087	310.3	376.2	82.5	85.48	70.5	27.3	46.6	47.9	1.0056	1.0056
18,000	0.841	1.030	0.189	306.6	359.8	85.2	77.53	66.1	28.1	51.1	53.7	1.0056	1.0058
21,600	1.241	1.471	0.230	262.8	304.3	86.4	81.46	70.4	30.9	59.1	61.8	1.0061	1.0062
25,200	1.075	1.266	0.191	253.3	282.4	89.7	82.22	73.7	31.1	57.3	59.7	1.0061	1.0061
28,800	0.898	1.086	0.188	217.5	253.3	85.8	79.06	67.8	30.3	54.1	56.7	1.0059	1.006
32,400	0.820	0.923	0.103	207.1	264.8	78.2	87.44	68.4	28.1	50.8	52.3	1.0057	1.0058
36,000	0.711	0.888	0.174	156.9	221.5	70.9	75.53	53.6	26.1	47.1	48.3	1.0056	1.0056
39,600	0.274	0.356	0.082	182.4	267.4	68.2	70.07	47.8	24.3	37.2	39.1	1.0052	1.0053

Table 10 Result of exergy analysis [onion] 2nd day

Time (s)	Ex_{dco} (KJ/kg)	Ex_{dci} (KJ/Kg)	Ex_{loss} (KJ/Kg)	Ex_{out} (w)	Ex_{rad} (w)	$\eta_{Ex.solar}$ %	$\eta_{Ex.do}$ (%)	$\eta_{Ex.net}$ (%)	T_a (°C)	T_{dco} (°C)	T_{dci} (°C)	$\bar{c}_p$(KJ/kg K)	
0	0.291	0.329	0.038	–	301.8	–	86.94	–	24.1	37.4	38.3	1.0052	1.0053
3600	0.170	0.233	0.063	96.64	190.8	50.6	62.94	31.8	27.7	37.9	39.7	1.0053	1.0054
7200	0.184	0.254	0.070	128.3	237.0	54.1	61.95	33.5	27.8	38.4	40.3	1.0054	1.0054
10,800	0.226	0.325	0.099	210.5	293.3	71.7	56.19	40.3	28.3	40.1	43.2	1.00543	1.0056
14,400	0.335	0.482	0.147	250.0	274.9	90.9	56.12	51.0	29.1	43.5	46.5	1.00553	1.0057
18,000	0.312	0.411	0.099	230.4	251.7	91.5	68.27	62.5	30.1	43.9	47.8	1.0056	1.0057
21,600	0.280	0.281	0.001	212.2	244.3	86.8	96.64	83.8	31.3	44.5	48.7	1.0056	1.0058
25,200	0.361	0.531	0.170	180.4	217.6	82.8	53.91	44.6	31.7	46.7	50.1	1.0057	1.0058
28,800	0.469	0.562	0.093	172.8	251.5	68.7	80.22	55.1	29.1	46.2	47.9	1.00564	1.0057
32,400	0.184	0.231	0.047	123.8	179.2	69.1	74.45	51.4	27.5	38.1	41.9	1.00535	1.0055
36,000	0.265	0.346	0.081	202.7	266.3	76.1	69.43	52.8	24.5	37.2	39.1	1.0052	1.0053
39,600	0.231	0.357	0.125	233.4	292.3	79.8	45.45	36.3	23.5	35.2	38.3	1.0051	1.0053

Table 11 Result of exergy analysis [onion] 3rd day

Time (s)	Ex_{dco} (KJ/kg)	Ex_{dci} (KJ/kg)	Ex_{loss} (KJ/kg)	Ex_{out} (w)	Ex_{rad} (w)	$\eta_{Ex.solar}$ (%)	$\eta_{Ex.do}$ (%)	$\eta_{Ex.net}$ (°C)	T_a (°C)	T_{dco} (°C)	T_{dci} (°C)	$\bar{c}_p$(KJ/kg K)	
0	0.265	0.382	0.117	–	297.4	–	55.85	–	24.5	37.2	39.8	1.0052	1.0053
3600	0.184	0.261	0.077	126.2	225.2	56.0	58.15	32.6	27.5	38.1	40.2	1.0053	1.0054
7200	0.321	0.414	0.093	171.8	214.5	80.1	70.92	56.8	29.1	43.2	45.2	1.0055	1.00561
10,800	0.347	0.432	0.085	132.6	171.1	77.5	75.51	58.5	35.1	49.9	52.1	1.0059	1.0060
14,400	0.914	0.959	0.045	137.4	178.9	76.8	95.10	73.1	36.1	50.7	53.2	1.0060	1.0061
18,000	0.762	0.931	0.169	861.5	1084.	79.4	77.82	61.8	37.9	60.1	63.3	1.0063	1.0065
21,600	0.843	1.068	0.225	145.8	185.9	78.4	73.31	57.5	35.7	59.0	62.1	1.0062	1.0063
25,200	0.816	1.038	0.222	145.6	188.9	77.1	72.79	56.1	35.3	58.2	61.3	1.0063	1.0063
28,800	0.349	0.538	0.189	137.1	207.8	66.0	45.84	30.3	29.4	44.1	47.8	1.0056	1.0057
32,400	0.399	0.576	0.177	157.4	217.8	72.3	55.63	40.2	27.5	43.2	46.5	1.0055	1.0056
36,000	0.291	0.381	0.090	175.8	221.4	79.4	69.10	54.9	26.3	38.1	41.7	1.0053	1.0054
39,600	0.234	0.326	0.092	217.3	271.2	80.1	60.68	48.6	24.2	36.1	39.2	1.0052	1.0053

Table 12 Result of exergy analysis [onion] 4th day

Time (s)	Ex_{dco} (kJ/kg)	Ex_{dci} (KJ/kg)	Ex_{loss} (KJ/kg)	Ex_{out} (w)	Ex_{rad} (w)	$\eta_{Ex.solar}$	$\eta_{Ex.do}$(%)	$\eta_{Ex.net}$	T_a (°C)	T_{dco} (°C)	T_{dci} (°C)	$\bar{c}_p$(KJ/kg K)	
0	0.295	0.395	0.100	–	289.8	–	66.01	–	24.5	37.9	40.1	1.0052	1.00532
3600	0.172	0.220	0.048	124.0	192.0	64.6	72.10	46.6	29.3	36.7	41.1	1.00536	1.00550
7200	0.210	0.301	0.091	119.0	203.3	58.5	56.66	48.4	31.1	42.3	44.8	1.0056	1.00570
10,800	0.889	0.901	0.012	158.2	222.8	71.0	96.65	70.0	32.3	54.6	56.2	1.0060	1.00600
14,400	0.895	1.200	0.305	168.5	188.2	89.5	65.92	59.0	34.9	58.9	63.4	1.0062	1.00630
18,000	1.283	1.416	0.133	199.8	233.7	85.5	89.63	76.6	33.4	62.2	64.9	1.0062	1.00633
21,600	1.161	1.351	0.19	211.8	249.3	84.9	83.63	71.0	31.9	59.2	62.8	1.0061	1.00620
25,200	0.775	0.961	0.186	226.8	307.7	73.7	76.00	56.0	28.9	52.4	56.1	1.0058	1.0060
28,800	0.931	1.150	0.219	170.8	229.7	74.3	76.48	56.8	28.1	52.3	55.2	1.0058	1.00591
32,400	0.698	0.858	0.16	142.4	192.3	74.0	77.07	57.0	27.9	48.8	51.2	1.0057	1.00580
36,000	0.641	0.832	0.191	154.6	228.6	67.6	70.20	47.5	25.9	45.7	47.3	1.0055	1.00560
39,600	0.456	0.615	0.159	187.2	302.5	61.9	65.13	40.3	23.4	40.1	42.9	1.0053	1.00534

Appendix D

Tables 13, 14, 15, 16, 17, 18, 19, 20, 21 and 22 show energy analysis and temperature of drying air at each tray inlet and exit as function of drying period of tomato, potato and onion drying.

Table 13 Result energy analysis tomato 1st day

Drying time (s)	T_{dci} (°C)	T_{dco} (°C)	Cpdci (KJ/kg. K)	cp_{dco} (KJ/kg K)	EUR (%)	*Ts*	T_a	*S* (w/m²)
0	36.1	34.5	1.0052	1.0052	12.2	18.5	24.5	452
3600	40	38.8	1.0054	1.0054	9.6	21.5	27.5	456
7200	44	41.1	1.00553	1.00544	17.7	21.6	27.6	567
10,800	56.8	53.8	1.0060	1.0059	11.3	24.1	30.1	854
14,400	56.4	53.6	1.0060	1.0059	10.8	24.2	30.2	602
18,000	50.1	49.8	1.0058	1.00578	1.65	24.1	30.1	805
21,600	50.2	49.2	1.00573	1.0057	4.72	22	28	914
25,200	58.2	56.8	1.0060	1.00595	4.8	22.7	28.7	823
28,800	53.4	52.2	1.0058	1.0058	4.9	22.8	28.8	607
32,400	45.8	42.1	1.0056	1.0055	19.9	21.1	27.1	578
36,000	42.3	40.1	1.0055	1.0054	14.5	21	27	529
39,600	40.1	38.4	1.0054	1.0053	12.0	20.6	26.8	478

Table 14 Result energy analysis tomato 2nd day

Drying time (s)	T_{dci} (°C)	T_{dco} (°C)	Cpdci (KJ/kg. K)	cp_{dco} (KJ/kg K)	EUR (%)	*Ts*	T_a	*S* (w/m²)
0	36.3	34.2	1.0051	1.005	14.9	16.1	22.1	553
3600	43	41.8	1.0054	1.0054	6.5	18.6	24.6	651
7200	47.8	46.9	1.0057	1.00544	5.4	23.5	29.5	763
10,800	53.8	52.1	1.006	1.0059	3.4	24.3	30.3	862
14,400	48.8	48	1.0059	1.0059	4.2	23.1	29.1	804
18,000	66.3	57	1.0063	1.00578	26.0	24.1	30.1	1056
21,600	55.3	53.1	1.0060	1.0057	9.4	24.9	30.9	998
25,200	49.9	48	1.0058	1.00575	3.9	23.9	29.5	832
28,800	49.8	47.1	1.006	1.0058	12.9	22.5	28.5	604
32,400	44.9	43.8	1.0056	1.0055	6.8	22.4	28.4	598
36,000	44.1	41.2	1.0055	1.0054	18.3	22.1	28.1	593
39,600	41.4	39.1	1.0055	1.0053	16.9	22.5	27.5	522

Table 15 Result energy analysis tomato 3rd day

Drying time (s)	T_{dci} (°C)	T_{dco} (°C)	Cpdci (KJ/kg. K)	cp_{dco} (KJ/kg K)	EUR (%)	*Ts*	T_a	*S* (w/m²)
0	34.5	32.8	1.005	1.005	11.6	15.3	21.3	489
3600	41.1	38.9	1.0053	1.0053	12.9	18.1	24.1	597
7200	43.8	42.9	1.0055	1.0055	5.6	21.6	27.6	757
10,800	58.1	56.2	1.0061	1.006	7.4	26.2	32.2	996
14,400	58.9	58.1	1.0061	1.0061	3.1	27.1	33.1	1042
18,000	56.8	55.1	1.0060	1.0060	6.8	26	32	1067
21,600	72.3	72.1	1.0066	1.0066	5.3	30.1	36.1	997
25,200	70	68.8	1.0065	1.0065	3.4	28.8	34.8	1005
28,800	60.2	59.1	1.0061	1.00611	3.9	25.8	31.8	684
32,400	53.9	50.8	1.0059	1.0058	12.8	23.6	29.6	582
36,000	49.2	47.2	1.0057	1.0056	9.8	22.5	28.5	523
39,600	47.1	44.3	1.0056	1.0055	11.1	21.1	27.1	512

Table 16 Result energy analysis potato 1st day

Drying time (s)	T_{dci} (°C)	T_{dco} (°C)	Cpdci (KJ/kg. K)	cp_{dco} (KJ/kg K)	EUR (%)	*Ts*	T_a	*S* (w/m²)
0	37.9	35.3	1.0052	1.0051	18.4	17.6	23.6	558
3600	45.9	44.1	1.0056	1.0055	10.0	21.7	27.7	663
7200	50.8	49.3	1.0058	1.0057	6.8	22.5	28.5	835
10,800	60.3	58.4	1.0061	1.006	6.11	22.7	28.7	885
14,400	61.0	60.1	1.0061	1.0061	3.0	23.3	29.3	1038
18,000	64.5	62.8	1.00625	1.0062	5.3	26.1	32.1	987
21,600	66.9	65.3	1.0063	1.0062	4.4	24.1	30.1	953
25,200	57.0	55.9	1.00602	1.006	4.1	24.0	30.0	856
28,800	50.1	49.1	1.0058	1.0057	5.0	23.5	29.5	823
32,400	46.1	44.5	1.0056	1.0056	9.14	22.6	28.6	602
36,000	42.1	38.4	1.0054	1.0053	18.42	20.3	26.3	523
39,600	38.3	34.2	1.0053	1.0051	19.4	18.2	24.2	487

Table 17 Result energy analysis potato 2nd day

Drying time (s)	T_{dci} (°C)	T_{dco} (°C)	Cpdci (KJ/kg. K)	cp_{dco} (KJ/kg K)	EUR (%)	*Ts*	T_a	*S* (w/m²)
0	40.3	35.3	1.0053	1.0051	28.9	16.9	22.9	479
3600	44.1	41.8	1.0053	1.0052	11.1	17.1	23.1	543
7200	49.3	42.5	1.0054	1.0053	25.9	19.5	25.5	602
10,800	58.2	50.2	1.0057	1.0056	25.9	21.3	27.3	860
14,400	60.1	51.2	1.0057	1.0057	27.5	21.7	27.7	891
18,000	62.8	58.2	1.0059	1.0058	13.3	22.1	28.1	981
21,600	65.1	62.1	1.0061	1.0061	8.8	24.9	30.9	908
25,200	57.9	55.9	1.0061	1.0060	7.4	24.5	30.5	856
28,800	54.8	49.1	1.0059	1.0059	23.3	24.3	30.3	690
32,400	51.8	44.5	1.0060	1.0057	31.1	22.1	28.1	585
36,000	47.3	38.4	1.0056	1.0055	42.3	20.2	26.2	512
39,600	46.3	34.2	1.0055	1.0054	45.6	18.5	24.5	498

Table 18 Result energy analysis potato 3rd day

Drying time (s)	T_{dci} (°C)	T_{dco} (°C)	Cpdci (KJ/kg. K)	cp_{dco} (KJ/kg K)	EUR (%)	*Ts*	T_a	*S* (w/m²)
0	37.5	34.3	1.0052	1.005	21.6	16.5	22.5	578
3600	44.0	40.8	1.0054	1.0053	16.2	18.1	24.1	654
7200	47.1	46.1	1.0055	1.0055	4.4	18.5	24.5	685
10,800	56.8	55.5	1.0059	1.0058	4.5	21.5	27.5	873
14,400	60.1	58.1	1.0061	1.0060	6.6	23.5	29.5	956
18,000	56.9	54.8	1.0059	1.0059	7.4	22.5	28.5	855
21,600	55.2	54.1	1.0059	1.0058	4.2	21.8	27.8	1017
25,200	59.6	58.1	1.006	1.006	4.8	22.4	28.4	856
28,800	55.3	54.3	1.0059	1.0059	3.9	23.5	29.5	688
32,400	55.1	54.2	1.0059	1.0058	4.3	22.8	28.8	584
36,000	47.9	44.7	1.0056	1.0055	14.9	17.3	26.3	542
39,600	41.2	38.3	1.0057	1.0052	18.1	18.5	24.5	512

Table 19 Result energy analysis onion 1st day

Drying time (s)	T_{dci} (°C)	T_{dco} (°C)	Cpdci (KJ/kg. K)	cp_{dco} (KJ/kg K)	EUR (%)	*Ts*	T_a	*S* (w/m²)
0	36.3	34.5	1.0052	1.0051	14.5	17.5	23.5	523
3600	38.1	35.7	1.0053	1.0052	18.0	18.5	24.8	697
7200	39.5	37.3	1.0053	1.0053	16.1	19.8	25.8	763
10,800	50.3	48.8	1.00573	1.0057	6.7	21.9	27.9	865
14,400	47.9	46.6	1.00564	1.0056	6.4	21.3	27.3	987
18,000	53.7	51.1	1.0058	1.0056	10.4	22.1	28.1	1023
21,600	61.8	59.1	1.0062	1.0061	8.8	24.9	30.9	1120
25,200	59.7	57.3	1.0061	1.0061	8.4	25.1	31.1	1057
28,800	56.7	54.1	1.006	1.0059	9.9	24.3	30.3	884
32,400	52.3	50.8	1.0058	1.0057	6.3	22.1	28.1	753
36,000	48.3	47.1	1.0056	1.0056	5.4	20.1	26.1	512
39,600	39.1	37.2	1.0053	1.0052	5.2	18.3	24.3	503

Table 20 Result energy analysis onion 2nd day

Drying time (s)	T_{dci} (°C)	T_{dco} (°C)	Cpdci (KJ/kg. K)	cp_{dco} (KJ/kg K)	EUR (%)	*Ts*	T_a	*S* (w/m²)
0	38.3	37.4	1.0053	1.0052	6.5	18.1	24.1	554
3600	39.7	37.9	1.0054	1.0053	15.2	21.7	27.7	654
7200	40.3	38.4	1.0054	1.0054	15.2	21.8	27.8	772
10,800	43.2	40.1	1.0056	1.00543	21.1	22.3	28.3	850
14,400	46.5	43.5	1.0057	1.00553	17.5	23.1	29.1	860
18,000	47.8	43.9	1.0057	1.0056	22.2	24.1	30.1	863
21,600	48.7	44.5	1.0058	1.0056	24.4	25.3	31.3	930
25,200	50.1	46.7	1.0058	1.0057	18.6	25.7	31.7	857
28,800	47.9	46.2	1.0057	1.00564	14.4	23.1	29.1	787
32,400	41.9	38.1	1.0055	1.00535	26.6	21.5	27.5	528
36,000	39.1	37.2	1.0053	1.0052	13.2	18.5	24.5	513
39,600	38.3	35.2	1.0053	1.0051	21.3	16.5	23.5	498

Table 21 Result energy analysis onion 3rd day

Drying time (s)	T_{dci} (°C)	T_{dco} (°C)	Cpdci (KJ/kg. K)	cp_{dco} (KJ/kg K)	EUR (%)	*Ts*	T_a	*S* (w/m^2)
0	39.8	37.2	1.0053	1.0052	17.2	18.5	24.5	573
3600	40.2	38.1	1.0054	1.0053	16.7	21.5	27.5	603
7200	45.2	43.2	1.00561	1.0055	12.6	23.1	29.1	671
10,800	52.1	49.9	1.0060	1.0059	13.1	29.1	35.1	879
14,400	53.2	50.7	1.0061	1.0060	14.7	30.1	36.1	988
18,000	63.3	60.1	1.0065	1.0063	12.8	31.9	37.9	1117
21,600	62.1	59.0	1.0063	1.0062	11.8	29.7	35.7	998
25,200	61.3	58.2	1.0063	1.0063	11.9	29.3	35.3	985
28,800	47.8	44.1	1.0057	1.0056	20.2	23.4	29.4	667
32,400	46.5	43.2	1.0056	1.0055	21.4	21.5	27.5	583
36,000	41.7	38.1	1.0054	1.0053	23.5	20.3	26.3	523
39,600	39.2	36.1	1.0053	1.0052	21.3	182	24.2	504

Table 22 Result energy analysis onion 4th day

Drying time (s)	T_{dci} (°C)	T_{dco} (°C)	Cpdci (KJ/kg. K)	cp_{dco} (KJ/kg K)	EUR (%)	*Ts*	T_a	*S* (w/m^2)
0	40.1	37.9	1.00532	1.0052	14.2	18.5	24.5	558
3600	41.1	36.7	1.00550	1.00536	37.4	23.3	29.3	612
7200	44.8	42.3	1.00570	1.0056	18.4	25.1	31.1	761
10,800	56.2	54.6	1.00600	1.0060	16.7	26.3	32.3	922
14,400	63.4	58.9	1.00630	1.0062	15.8	28.9	34.9	953
18,000	64.9	62.2	1.00633	1.0062	8.3	27.4	33.4	1056
21,600	62.8	59.2	1.00620	1.0061	11.7	25.9	31.9	998
25,200	56.1	52.4	1.0060	1.0058	13.8	22.9	28.9	845
28,800	55.2	52.3	1.00591	1.0058	10.8	22.1	28.1	653
32,400	51.2	48.8	1.00580	1.0057	10.4	21.9	27.9	533
36,000	47.3	45.7	1.00560	1.0055	9.6	19.9	25.9	517
39,600	42.9	40.1	1.00534	1.0053	14.4	17.4	23.4	507

Received: 17 September 2019 Accepted: 20 May 2020
Published online: 08 August 2020

References

Akpinar, E. K. (2004). Energy and Exergy Analyses of drying red pepper slices in a convective type dryer. *International Communications in Heat and Mass Transfer*, *31*(8), 1165–1176.

Akpinar, E. K. (2010). Drying of mint leaves in a solar dryer and under open sun: Modelling, performance analyses. *Energy Conversion and Management*, *51*(12), 2407–2418.

Akpinar, E. K., Midilli, A., & Bicer, Y. (2006). The first and second law analyses of thermodynamic of pumpkin drying process. *Journal of Food Engineering.*, *72*(4), 320–331.

Amjad, W., Hensel, O., Munir, A., Esper, A., & Sturm, B. (2016). Thermodynamic analysis of drying process in a diagonal-batch dryer developed for batch uniformity using potato slices. *Journal of Food Engineering, 169,* 238–249.

Arepally, D., Ravula, S. R., Malik, G. K., & Kamidi, V. R. (2017). Mathematical modelling, energy and exergy analysis of tomato slices in a mixed mode natural convection solar dryer. *Chemical Science International Journal, 20*(4), 1–11.

Bennamoun, L. (2012). An Overview on Application of Exergy and Energy for Determination of Solar Drying Efficiency. *International Journal of Energy Engineering, 2*(5), 184–194.

Bhardwaj, A. K., Chauhan, R., Kumar, R., Sethi, M., & Rana, A. (2017). Experimental investigation of an indirect solar dryer integrated with phase change material for drying valeriana jatamansi (medicinal herb). *Case Studies in Thermal Engineering, 10,* 302–314.

Bolaji, B. O., & Olalusi, A. P. (2008). Performance evaluation of a mixed-mode solar dryer. *Journal of Agricultural Biotechnology and Sustainable Development, 11*(4), 225–231.

Borah, A., Hazarika, K., & Khayer, S. M. (2015). Drying kinetics of whole and sliced turmeric rhizomes (*Curcuma longa* L.) in a solar conduction dryer. *Information Processing in Agriculture, 2*(2), 85–92.

Celma, A. R., & Cuadros, F. (2009). Energy and exergy analyses of OMW solar drying process. *Renew. Energy, 34*(3), 660–666.

Darvishi, H., Azadbakht, M., & Noralahi, B. (2018). Experimental performance of mushroom fluidized-bed drying: Effect of osmotic pretreatment and air recirculation. *Renewable Energy, 120,* 201–208.

El-sebaii, A. A., & Shalaby, S. M. (2012). Solar drying of agricultural products: A review. *Renewable and Sustainable Energy Reviews, 16*(1), 37–43.
Fudholi, A., Sopian, K., Yazdi, M. H., Hafidz, M., Gabbasa, M., & Kazem, H. A. (2014). Performance analysis of solar drying system for red chili. *Solar Energy, 99,* 47–54.
George, C. (2007). Determination of Optimal Surface Area to Volume Ratio for Thin-Layer Drying of Breadfruit (Artocarpus altilis). *Humanitarian Engineering and Social Entrepreneurship., 2*(2), 76–88.
I. S. U. N. Drying. 2006. 33 Sun and solar drying, techniques and equipment ii. solar drying II. 1. Types of Solar Dryers 1, 1–8.
ILRI. 2005. Fogera Woreda pilot learning site diagnosis and program design.
Kalaiarasi, G., Velraj, R., & Swami, M. V. (2016). Experimental energy and exergy analysis of a flat plate solar air heater with a new design of integrated sensible heat Storage. *Energy, 111,* 609–619.
Karim, M. A. (2004). Development of solar air collectors for drying applications. *Energy Conversion and Management, 45,* 329–344.
Minaei, S., Chenarbon, H. A., Motevali, A., & Hosseini, A. A. (2014). Energy consumption, thermal utilization efficiency and hypericin content in drying leaves of St John's Wort (Hypericum perforatum). *Journal of Energy in Southern Africa, 25*(3), 27–35.
Mustayen, A. G. M. B., Mekhilef, S., & Saidur, R. (2014). Performance study of different solar dryers: A review. *Renewable and Sustainable Energy Reviews, 34,* 463–470.
N. Resource and R. Development. 2016. Tropentag 2016, Vienna, Austria September 18–21, 2016.
Niksiar, A., & Rahimi, A. (2009). Energy and exergy analysis for cocurrent gas spray cooling systems based on the results of mathematical modeling and simulation. *Energy, 34*(1), 14–21.
Oztop, H. F., Bayrak, F., & Hepbasli, A. (2013). Energetic and exergetic aspects of solar air heating (solar collector) systems. *Renewable and Sustainable Energy Reviews, 21,* 59–83.
Prommas, R., Rattanadecho, P., & Cholaseuk, D. (2010). Energy and exergy analyses in drying process of porous media using hot air. *International Communications in Heat and Mass Transfer, 37*(4), 372–378.
S. B. Wassie. 2016. Amhara region horticulture development. 2019.
Sami, S., Etesami, N., & Rahimi, A. (2011). Energy and exergy analysis of an indirect solar cabinet dryer based on mathematical modeling results. *Energy, 36*(5), 2847–2855.
Singh, S., & Kumar, S. (2012). Testing method for thermal performance based rating of various solar dryer designs. *Solar Energy, 86*(1), 87–98.
Tripathy, P. P., & Kumar, S. (2009). Modeling of heat transfer and energy analysis of potato slices and cylinders during solar drying. *Applied Thermal Engineering, 29*(5), 884–891.
Zohri, M., Hadisaputra, S., & Fudholi, A. (2018). Exergy and energy analysis of photovoltaic thermal (Pvt)with and without fins collector. *ARPN, 13*(3), 803–808.

Publisher's Note