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Evaluation of a naturally ventilated solar-venturi dryer environmental effect on the quality of dried sweet-potato slices

Siyabonga Gasa[1, 2]*, Sipho Sibanda[1], Tilahun S Workneh[2], Mark Laing[2] and Alaika Kassim[2]

[1]Institute for Agricultural Engineering, Agricultural Research Council, Private Bag X519, Pretoria, South Africa.
[2]Descipline of Bioresources Engineering, School of Engineering, University of KwaZulu-Natal, Private Bag X01, Pietermaritzburg, South Africa.

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A naturally ventilated solar-venturi dryer (NSD) was constructed using locally available materials to improve the quality of dry sweet potato slices (SPS) for small to medium scale farmers. The study investigated the efficiency of the NSD to reduce relative humidity (RH), solar radiation and temperature effect on firmness and color of dried SPS. The maximum temperature inside NSD was 44.4°C (12:00 pm) in an empty dryer and 34.1°C (13:00 pm) for a full filling NSD. The minimum RH in an empty dryer was 13.5 and 15.1% for a full filling NSD. The NSD was able to increase the temperature and reduce the RH at a minimum and maximum efficiency of 38.5 and 84.9% in a fulfilling NSD and 35.2 and 77.6% in an empty NSD. Thickness size and pre-treatment method had a significant (p<0.05) influence on color and firmness of dried SPS. The design of an NSD allows small to medium-scale farmers to process and preserve their produce at low cost, using the already available materials and structures.

Key words: Solar radiation; color; firmness, efficiency.

INTRODUCTION

The awareness for the adoption of technologies to agricultural processing including agro-processing and value addition like drying of agricultural products is increasing globally (Fudholi et al., 2014; Lingayat et al., 2017). Literature reports a potential for harvesting solar energy for agricultural processing (Pirasteh et al., 2014; Phadke et al., 2015). Miraei et al. (2017), and Rabha and Muthukumar (2017) reported that solar energy can provide the required temperature for drying of agricultural produce. However, solar energy remains untapped in the south, mainly in the African countries (El-Sebaii and Shalaby, 2012; Chouicha et al., 2013).

Developing countries with poorly established thermal drying and processing facilities face challenges of closing the gap between the gross food produced and the net food available because of post-harvest losses (Bolaji and Olalusi, 2008; Madrid, 2011; Mustayen et al., 2014). These losses include those in the field, during storage, and processing and these are estimated between 20-50% in Africa (Abass et al., 2014). The postharvest

*Corresponding author. E-mail: ciahgasa@gmail.com. Tel: 012 842 4039.

losses of cereals are estimated at 25%, while that of fruits and vegetables are 50% (Kiaya, 2014). To reduce such losses, small-scale farmers use sun drying. However, traditional sun drying is fraught with challenges, such as being highly dependent on the weather, as well as the threat of contamination.

Among numerous methods used for food preservation, drying is the most ancient and commonly used method. The main objective of drying is to increase shelf life and preserve food by reducing moisture content. Open sun drying has been used for the partial removal of water (Madhlopa and Ngwalo, 2007). However, several drawbacks, such as prolonged drying time, microbial contamination, and dust result in a poor final dried product (Kiaya, 2014; Lingayat et al., 2017). Therefore, hot air drying becomes an alternative drying technology used for dehydration. However, it has a several limitations, such as its high energy input requirements and cost (Meher and Nayak, 2015; Miraei et al., 2017).

The drying method and equipment have an impact on the final product; hence there is a need to study the effect of the drying method on the quality of chips after drying (Luther et al., 2004). Convective hot-air drying is the most common method of drying agricultural crops both for industrial and commercial purposes. Studies report that drying influences the physical and chemical properties and quality of dried sweet potato slices (Dinrifo, 2012; Mujumdar, 2012). Doymaz (2011) reported that heat and mass transfer during the drying process cause browning color of the product resulting in poor quality compared to the original food.

On average, South Africa has 2 500 h of sunshine per year and an average solar radiation of 4.5 to 6.5 $kWh.m^{-2}$ per day (Qase et al., 2015). Hence, there is a potential for harvesting solar energy. Disadvantages arising from traditional open sun drying have led to the development of both active and passive conventional solar dryers. These dryers can further be sub-divided into the direct, indirect, and mixed mode solar dryers. Direct solar dryers have prolonged drying time and as such, indirect solar dryers were developed to ensure a reduced drying time. Sontakke and Salve (2015) conducted a study on indirect solar drying of apricots using a small dish solar heater that was connected to a drying chamber. The study concluded that, indirect solar dryers are able to increase the drying efficiency of a direct solar dryer from 20% at a natural flow rate of 0.01 $kg.s^{-1}$ to 42.6% at a convective flow rate of 0.21 $kg.s^{-1}$. The study reported that dehydration of apricot from 85 to 8% moisture content took 13 h. However, these dryers are linked with high-energy prices.

Use of solar chimney dryers is gaining momentum in agriculture because of the increasing energy prices and the importance of environmental protection. This drying system uses solar energy to heat ambient air to dry agricultural products. The principle of solar chimney drying combines wind-driven ventilation and a solar stack. This provides free convection, permitting good air speed and the uniform distribution of hot air inside the drying chamber (Maia et al., 2011; Afriyie and Bart-Plange, 2012). However, existing literature shows that the use of solar-venturi drying for agricultural produce under South African conditions remains untapped. In addition, South Africa has a lack of research on hot-air drying methods, as well as their performance when drying sweet potato slices (SPS). With the current shift in use of renewable energy for drying operations, this research is focusing on promoting the development of a small-scale naturally ventilated solar-venturi dryer (NSD) that is suitable for Southern African agro-climatic conditions. This is seen as one of the options that can be adopted to help alleviate food insecurity. Therefore, the main aim of this study was to develop a low-cost drying technology that can be adopted by small scale producers for use in South African, Pietermaritzburg climatic conditions. The objective of this study was to characterize the air temperature and relative humidity (RH) inside the NSD and evaluate its effect on dried sweet potato slices (SPS), evaluate the effect of drying method (NSD and HAD) and SPS thickness size and effect of pre-treatment on the quality of dried SPS slices.

Availability of solar energy in South Africa

Solar energy is a source of renewable energy, which is attributed to sunlight. It is the energy emitted from the sun's radiation at the rate of 3.8×10^{23} kW. Of this energy 1.8×10^{4} kW is intercepted by the earth. Solar energy is the most readily available renewable energy source in South Africa for both heating and electricity (Qase et al., 2015). Solar energy has several benefits, such as tax credits, feed-in-tariff, preferential interest rates and green power programs; however, some technical and financial barriers, like low efficiency and high capital costs, need to be overcome (Timilsina et al., 2012). Solar energy represents the largest source of renewable energy, compared to biomass, biogas, wind and geothermal sources. Solar energy is environmental-friendly and is viewed as a promising heat source that meets the high-energy demands, without having an adverse impact on the environment (Tyagi et al., 2012).

Fluri (2009) studied the availability of solar energy and the potential for implementing solar power plants in all the provinces of South Africa, which can be identified by using Geographical Information System (GIS). The total nominal capacity of the country was found to be 547.6 GW, with the identified areas being able to accommodate solar power plants with a nominal capacity of 510.3 GW in the Northern Cape Province, 10.5 GW in Western Cape, 25.3 GW in the Free State and 1.6 GW in the Eastern Cape Province (Fluri, 2009). The study implies that there is enough solar energy in South Africa, which can be converted to heat, or electricity for thermal and

Figure 1. (a) Drying chamber of a modified naturally ventilated solar-venturi dryer and (b) hot air oven dryer.
Source: Authors

electrical applications. The potential for the application of solar energy is for preservation of horticultural commodities, such as fruits and vegetable through cool storage and drying exists.

MATERIALS AND METHODS

The study was conducted to evaluate the effect of the two drying methods and pre-treatments on the quality of dried sweet potato slices based on the following materials and methods.

Study site and climatic data

The study was conducted at the Ukulinga Research Farm, University of KwaZulu-Natal, Pietermaritzburg, South Africa (29.7°S and 30.4°E at an altitude of 721 m above sea level). The area has mean long-term minimum and maximum temperatures of 6.0-16.4°C and 20.6-27.4°C, respectively, and a RH of 61.1-75.3%. The area receives mean solar radiation of 15.1-27.8 $MJ.m^{-2}.day^{-1}$, which is sufficient for solar drying applications (Schulze and Maharaj, 2007).

The study was conducted in September 2018. The mean long-term minimum and maximum temperature in September is 10.0-17.1°C and 12.0-27.0°C, respectively, while the RH is 61.1-68.1%. The mean solar radiation, wind speed and mean sunshine hours for September are 15.1-27.8 $MJ.m^{-2}.day^{-1}$, 0.8-9.7 $m.s^{-1}$ and 7 hours, respectively (Schulze and Maharaj, 2007). The weather data (temperature, RH, solar radiation, and wind speed) recorded during the study period was obtained from the weather station at the Ukulinga Research Farm.

Sample preparation

A batch of fresh sweet potato storage roots was purchased from a local supermarket in Hayfields, Pietermaritzburg, South Africa. Sweet potato storage roots with no physical damage and no sign of fungal or microbial infection were selected. The selected storage roots were peeled, using a carbon steel blade potato peeler, after which they were washed, using deionized water. The peeled sweet potato storage roots were dabbed, using paper towels to remove water on their surface. Thereafter, the sweet potato storage roots were sliced into rectangular shapes with the dimensions of, 50 by 20 mm, using a stainless-steel kitchen knife (Oke and Workneh, 2014). The thickness sizes of the slices were 3, 5 and 7 mm. The slices were pre-treated by either; (a) dipping in an iodate table salt solution (0.1% w/v concentration for 20 minutes); (b) lemon juice solution (1% w/v concentration for 20 min); (c) blanched in a water bath at 70°C for 10 minutes (using Labotech water bath, Thermo Fisher Scientific, Waltham, Massachusetts, United States); and (d) the batch of control samples was not pre-treated. The treated samples were dabbed using paper towels to remove any free liquid from their surface (Olawale and Omole, 2012).

Drying methods and experimental setup

The prepared pre-treated and control sweet potato slices samples were subjected to drying using a naturally ventilated solar-venturi dryer and a hot air oven dryer using methodology described in Gasa et al. (2022). In NSD, mango slices were placed on top of a 0.54 m^2 perforated wire mesh inside the drying chamber shown in Figure 1 (a) while other samples were placed in a HAD shown in Figure 1 (b). The drying in NSD was regulated by the study site climatic data while drying in HAD experiments were performed at a fixed temperature of 70°C.

Description of a naturally ventilated solar-venturi dryer

The constructed NSD consisted of three main parts, a solar collector, drying chamber and solar chimney as shown in Figures 2 and 3. The ambient air entered the lower side of the solar collectors (roof) and rose to the top side because of the venturi effect. The solar collectors' heat ambient air and directed it upwards before

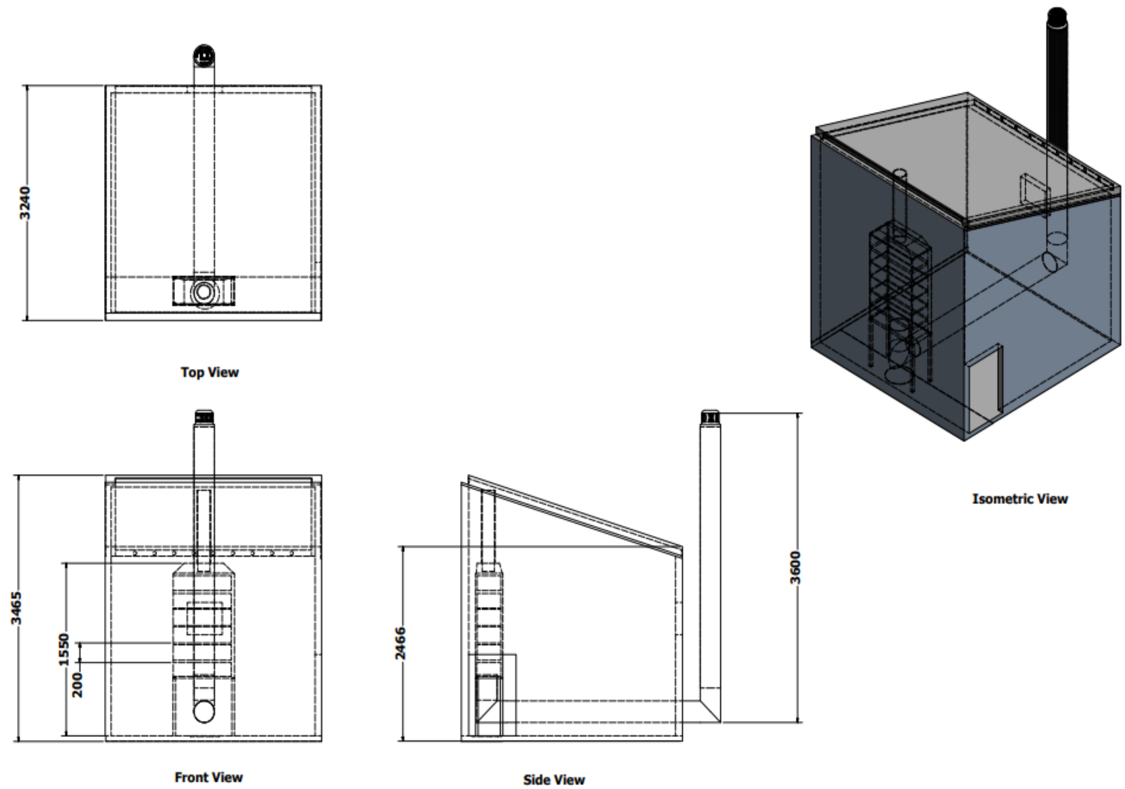

Figure 2. Naturally ventilated solar-venturi dryer.
Source: Authors

entering the drying chamber. The heated air then flowed through the drying chamber because of the negative suction created by the solar chimney and the whirlybird at the bottom of the drying chamber as shown in Figure 3.

The solar radiation collector was made from locally sourced materials like galvanized corrugated iron sheet (760 mm x 3500 mm x 1 mm). The emissivity and absorptivity of galvanized steel were 0.13 and 0.65, respectively (Sanni et al., 2012). The galvanized corrugated iron sheet was painted black to increase the absorption of the available solar irradiation. Painting the galvanized corrugated iron sheet black can increase its absorptivity up to 0.90 (Sanni et al., 2012; Seidu et al., 2012). A clear polycarbonate sheet (750 mm x 3600 mm x 1 mm) was placed on top of the galvanized corrugated iron sheet, with a clearance of 100 mm, as shown in Section-A of Figure 2. The polycarbonate sheet was supported by a rectangular steel bar frame, with a cross-section of 3 mm x 100 mm. Polycarbonate sheeting has a transmittance of 0.80. The ambient air entered the solar collector through the circular inlet (50 mm diameter) at the lower side of the solar collector. The inlets were spaced at 100 mm from center to center, as shown in Section A and exit from a circular opening (150 mm diameter) on the elevated side of the solar collectors to the drying chamber.

The drying chamber with the dimension of 900 mm x 600 mm x 1450 mm, was constructed using angle bars (25 mm x 25 mm x 5 mm), as shown in Figures 1. The steel frame was enclosed with 9.5 mm thick plywood. The drying chamber was fitted with six (900 mm x 600 mm) equally spaced trays (200 mm apart) made of wire mesh (with an aperture size of 0.23 by 0.23 mm). The drying chamber had two circular (150 mm in diameter) air inlets at the top, which connected to the solar collector through two 1100 mm long cylindrical pipes, each with a diameter of 150 mm. The air exited the drying chamber through a 300 mm diameter hole at the bottom that was connected to the solar chimney using an L-shaped galvanized steel cylindrical pipe with a diameter of 300 mm.

The solar chimney was made of galvanized steel with the height of 3 600 mm and a diameter of 300 mm (Figure 2). The solar chimney was painted black. A whirlybird with a diameter of 250 mm in diameter connected by using a ducting reducer from 300 to 250 mm.

Efficiency of a naturally ventilated solar-venturi dryer

The air velocity, temperature, and RH inside the drying chamber as well as the ambient temperature and RH were recorded using hobo ware data loggers to determine the performance of a solar-venturi dryer. The air temperature and RH inside the NSD drying system were measured at four points, namely: A (at the exit of the solar collector), B (at the inlet of the drying chamber), C (at the center of the drying chamber), and D (at the exit of the drying chamber). Hobo ware data loggers (Model U23-001, Onset, Cape Cod, USA) were used to measure the temperature and RH with an accuracy of ±0.21°C and ±2.5%, respectively. The data loggers were placed (two at each measuring point A, B, C and D) as shown in Figure 4. The air velocity was measured at the center of the drying chamber, using a Heavy-Duty Hot Wire Thermo-Anemometer (Extech instruments, Massachusetts, United States). In a loaded drying experiment (dryer with samples) each tray was loaded with 2.7 kg of SPS in each experiment. The performance evaluation of the solar collector was evaluated using (Equation 1) (Abdellatif et al., 2015).

$$q_a = R \times A_c \quad (1)$$

Where: R = solar radiation flux incident [$W.m^{-2}$], A_c = area of the

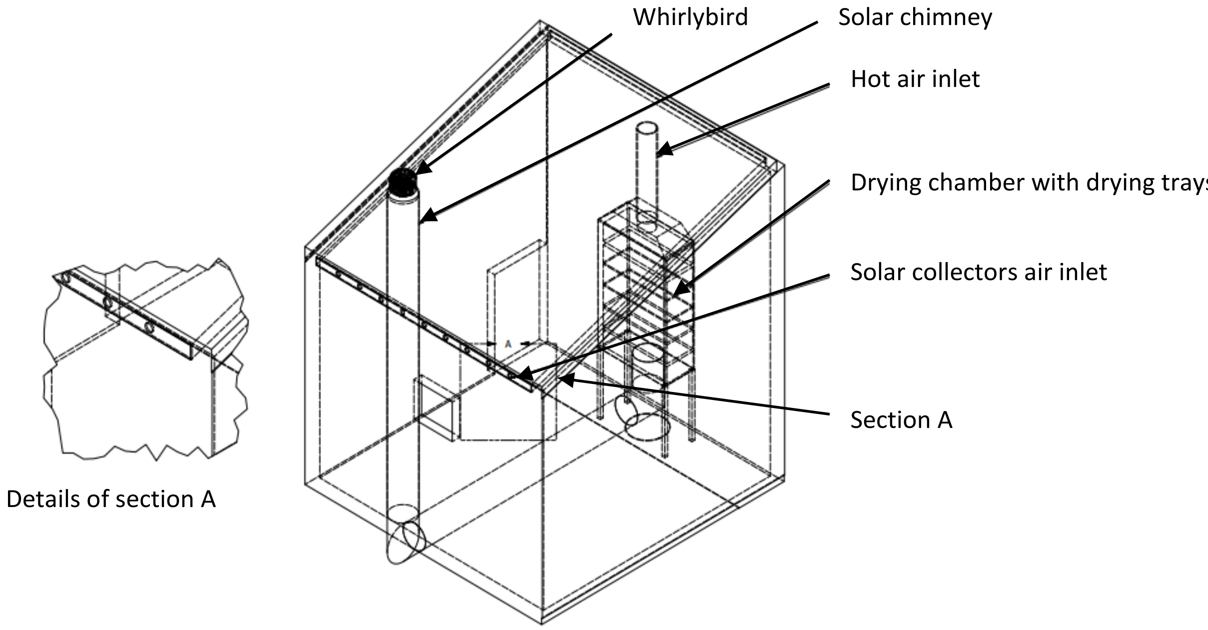

Figure 3. Isometric view of a naturally ventilated solar-venturi dryer.
Source: Authors

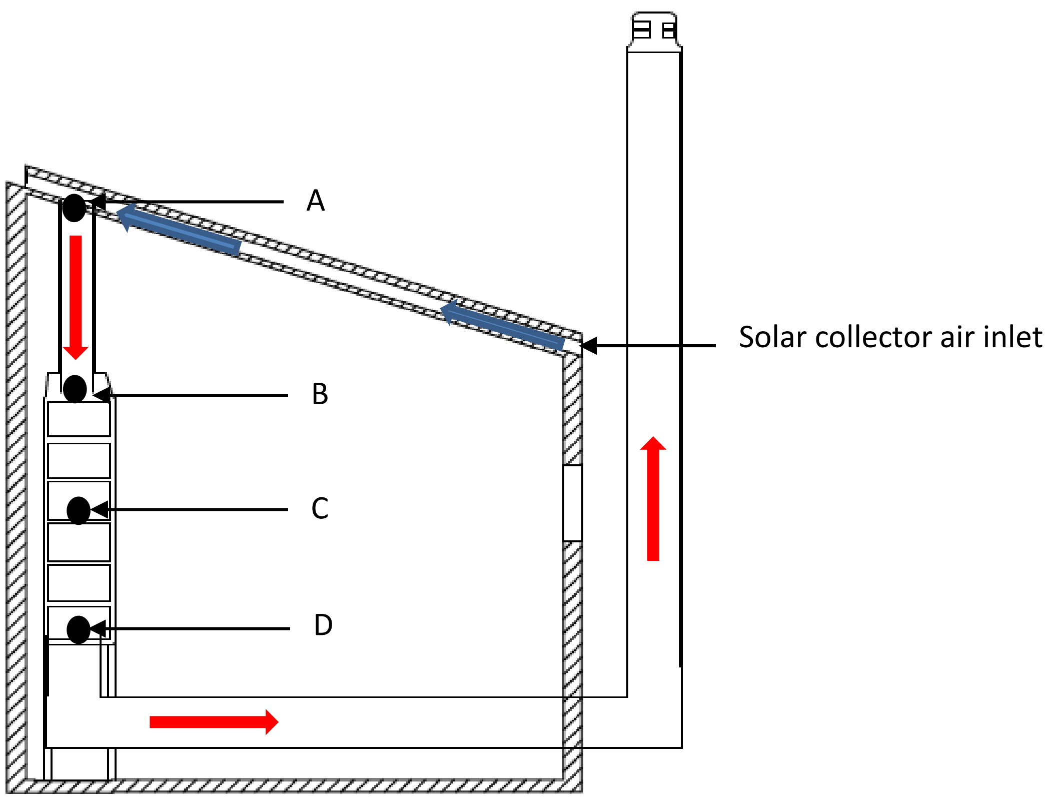

Figure 4. Illustration of air flow and data collection points inside the solar dryer (*A = exit of the solar collector, B = inlet of the drying chamber, C = center of the drying chamber and D = exit of the drying chamber).
Source: Authors

solar collector [m^2], and q_a = solar energy available [W].

The useful heat gained in the solar collector was calculated using (Equation 2) (Abdellatif et al., 2015).

$$q_u = \dot{m} c_p (T_e - T_i) \quad (2)$$

Where: q_u = heat gained by the air [W],$\dot{m}$ = mass flow rate of air [$kg.s^{-1}$], c_p = specific heat of air [=1.006 $kJ.kg.^{o}C^{-1}$], T_i = temperature at the inlet of the solar collector [C], and T_e = temperature at the exit of the solar collector [C].

The overall thermal efficiency of the solar collector was calculated as shown in (Equation 3) (Abdellatif et al., 2015).

$$\eta_c = \frac{q_u}{q_a} \times 100 \quad (3)$$

Where: η_c = solar collector efficiency [%] and A_c = area of the solar collector [m^2].

Firmness analysis

A commercial hot-air oven dryer (HAD) and naturally ventilated solar-venturi dryer (NSD) was used to dry SPS, with hot-air oven dryer used to evaluate the effect of drying method on firmness and fracturability of dried sweet potato slices.

Firmness and fracturability were measured using TA.XTplus Texture Analyzer (Vienna Court, Lammas Road, Godalming, Surrey GU7 1YL, UK) with a 0.5 kN loading capacity. This was used to determine the maximum breaking force of both the NSD and a HAD sweet potato slice, using methodology described by Pedreschi and Moyano (2005). The test was carried out using a 2 mm stainless steel probe, attached to a load cell, at a penetration rate of 1 $mm.s^{-1}$ and a penetration depth of 8 mm.

Color analysis of dried sweet potato slices

The color of dried sweet potato chips was determined, using Colorflex EZ's 45°/0° colorimeter. The color properties of the samples before and after drying were measured and compared to the color of fresh SPS. Colorflex was calibrated against a black and white standardization tile, before taking the actual measurements. Color measurements were carried out in terms of CIE L*a*b color measurements. Lightness, L* indicates the color coordinate of lightness (ranging between zero (black) and hundred (white). Redness, a* indicates the color coordinate of redness (+ = red and - = green) and b* indicates the color coordinates of yellowness (+ = yellow and - = blue). During the color test, three measurements were taken from different positions in each sample, and the average value was determined.

RESULTS AND DISCUSSION

The ambient air-conditions (temperature, RH and solar radiation) measurements were taken on hourly basis during the experimental month (September 2018). The experiments for the natural-ventilated solar-venturi dryer were divided into empty (dryer with no samples) and a loaded drying (dryer with drying samples).

Efficiency assessment of a naturally ventilated solar-venturi dryer

The average minimum and maximum ambient temperatures recorded during empty NSD experiment were 23.3 and 26.4°C, respectively recorded at 8:00 am and 14:40 pm, from 2-6 September 2018, as shown in Figure 5. During which the solar radiation increased from a minimum of 388.0 $W.m^{-2}$, recorded at 8:00 am, to a maximum of 894.3 $W.m^{-2}$, recorded at 12:00 pm, beyond which it gradually reduced to the 742.7 $W.m^{-2}$. The minimum and maximum average ambient temperatures for a fully-loaded NSD experiment recorded from 9-20 September 2018 was 20.2°C and 22.4°C, respectively as shown in Figure 6. Solar radiation recorded during this period was 546.9 $W.m^{-2}$ at 8:00 am, increasing to a maximum of 889.7 $W.m^{-2}$ during midday (12:00-13:00 pm). The solar radiation intensity was observed to have a bell-shape, with the maximum intensity occurring at midday (12:00-13:00 pm). This was expected as at midday the sun is overhead and its path is shortened. At midday, less solar radiation is scattered or absorbed by atmospheric mediums, and more direct radiation reaches the solar collectors compared to anytime of the day which is like findings of Schulze and Maharaj (2007) and Lingayat et al. (2017). The variation of solar radiation and the ambient air temperature significantly affect the NSD temperature. The ambient temperature was less than the temperature inside the drying chamber with an average temperature gradient of 12.4°C. This is similar to the findings by Hegde et al. (2015) who observed a temperature difference of 11°C in a solar dryer. The NSD temperature remained higher than the ambient temperature. The maximum air temperature and minimum RH inside the drying chamber was observed at the highest solar radiation intensity (Berinyuy et al., 2012; Kolawole, 2013). Ekici and Teke (2018) found that factors, such as the season and time of the day, are important parameters that determine the amount of solar radiation received at a location. However, it is also affected by the presence of clouds and turbidity in the atmosphere.

The increase in temperature inside the NSD was directly proportional to the increase in ambient temperature, and it was inversely proportional to the RH inside and the ambient RH. The increasing ambient temperature causes decreased RH values for ambient conditions and inside the NSD. As a result, minimum RH values were observed during midday (12:00-13:00 pm). The ambient RH was always higher than the NSD relative humidity due to increased temperature inside the dryer. As the temperature inside the dryer increased, the heated air from the solar collectors could hold larger amount of water vapor and therefore, the RH decreased. Mkhathini et al. (2018) reported that the lowest RH values in solar drying occurred during midday at high ambient temperature. The results obtained in this study show that, there was a significant ($p<0.05$) high temperature and RH difference between the ambient conditions and the inside of the NSD. The bottom tray had a lower temperature compared to the top tray, which indicates that heat was

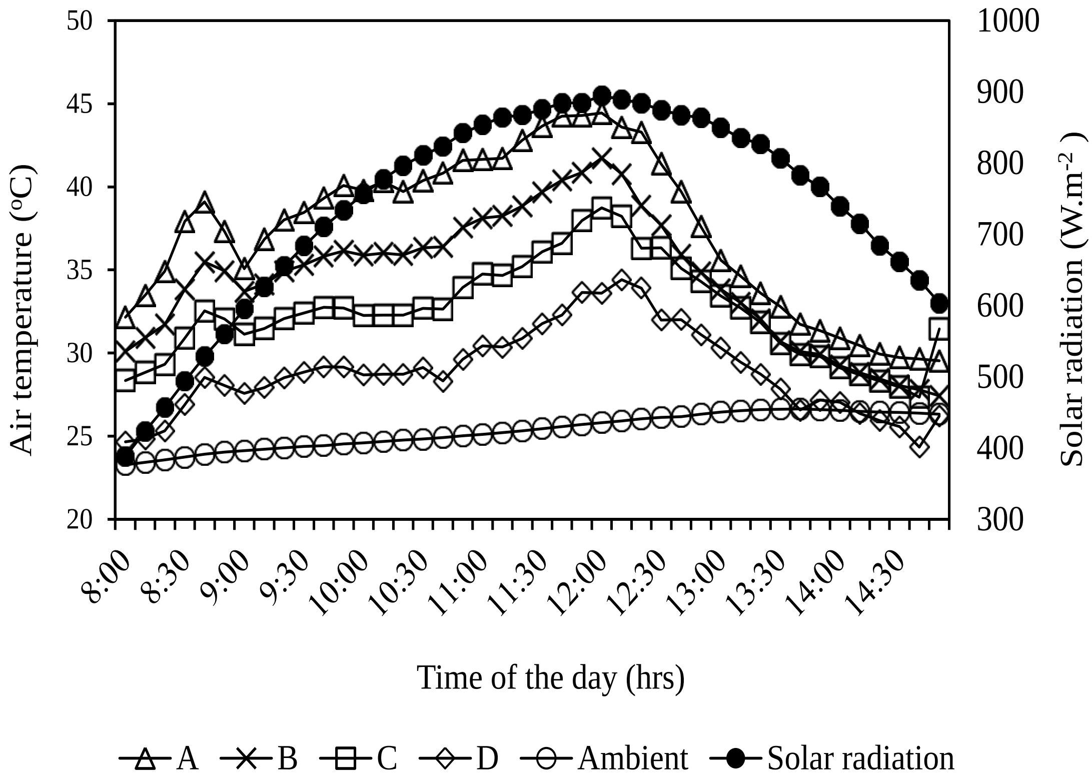

Figure 5. Average daily variation of air temperature and solar radiation in an empty dryer (A=exit of the solar collector, B= inlet of the dryer chamber, C= center of the drying chamber, D= exit of the drying chamber, Ambient= Ambient temperature.
Source: Authors

lost as the air moved inside the drying chamber and through the moist drying samples. This may have resulted from the increase in water vapor content and the RH because cold air does not require as much moisture to be saturated as warmer air (Khiari et al., 2004). Khiari et al. (2004) reported that an optimum temperature for food water removal is 80ºC and if higher temperatures are used, the food will cook instead of drying. The results in this study show that the drying temperature was always less than 80ºC, implying that drying is still possible below this temperature, however, the time to complete drying maybe longer. However, it is possible to reduce the drying time by increasing the airflow rate. Therefore, the close relationship between the ambient and NSD is very important.

The ambient RH and the RH recorded during empty NSD experiment inside the solar-venturi dryer are shown in Figure 7. The minimum RH at the exit of the solar collector, inlet, centre and exit of the drying chamber were 13.5, 15.2, 18.4 and 28.4% respectively, recorded at 12.00 pm. In the fully-loaded drying experiment, minimum RH was observed at midday at all measuring points (inlet, center and exit of the drying chamber) and was measured to be 15.1, 18.4 and 26.6%, respectively as shown in Figure 8. The RH increased as the heated air flowed from the inlet of the drying chamber to the exit. This means that the solar-venturi dryer was able to raise the air temperature and reduce the air RH under the environmental conditions obtaining in Pietermaritzburg.

The collector efficiency signifies the utilized heat against the heat input in the form of solar insolation. The maximum efficiency of the solar collector was observed at the maximum insolation (at midday) as shown in Figure 8 and 9. Thermal efficiency of the solar dryer was observed to be dependent on the solar radiation intensity and wind speed and direction. Useful heat gain is dependent on the air mass flow rate and the difference in temperature between the ambient air entering and leaving the solar collectors. Thermal efficiency decreased as the solar radiation decreased.

Firmness analysis

The results showed that the drying method and pre-treatments had a significant ($P<0.05$) effect on the physical properties of dried SPS. Table 1 shows the firmness of SPS using HAD and NSD pre-treated. Sweet potato slices dried using HAD had firmness values of 8.8±0.8 – 38.3±3.5 N. The average firmness of SPS dried

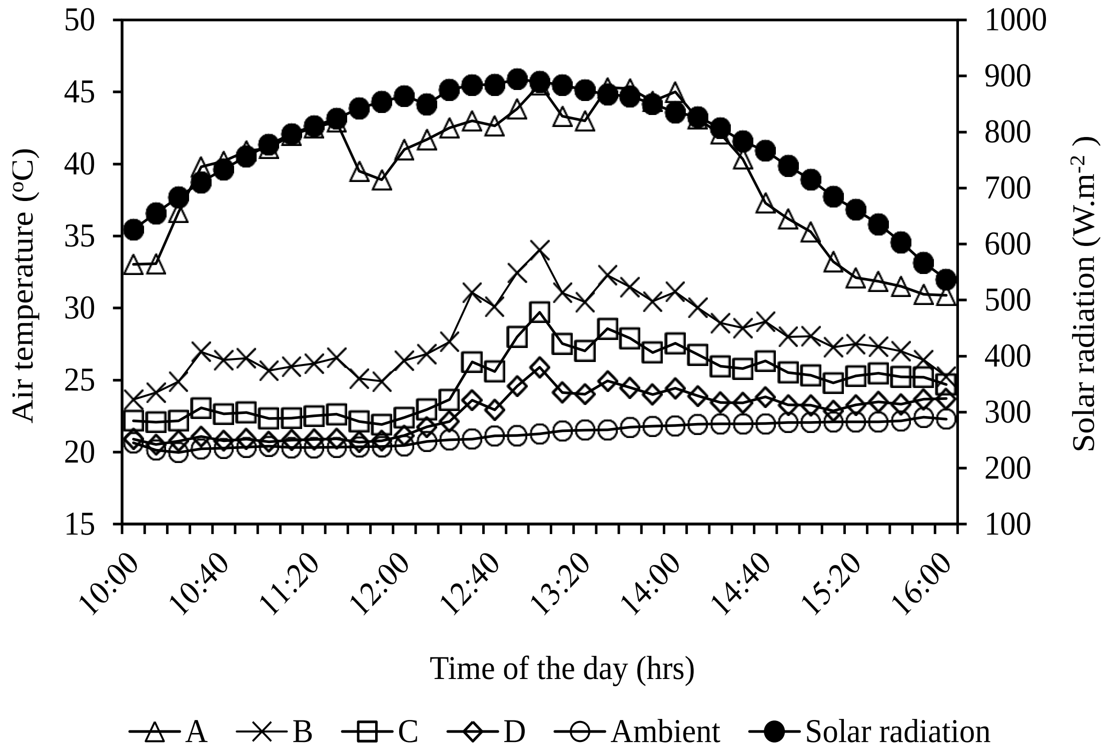

Figure 6. Average daily variation of air temperature and solar radiation in a full filling loaded solar dryer (A = exit of the solar collector, B = inlet of the drying chamber, C = center of the drying chamber, D = exit of the drying chamber, Ambient = ambient temperature.
Source: Authors

in HAD at 3, 5 and 7 mm thickness were 14.5±1.9, 21.5±2.6 and 27.4±3.3 N, respectively. Control samples with 3 mm thickness had lower firmness values compared to all treatments. However, for 5- and 7-mm thickness lemon juice pre-treated samples had lower firmness values followed by salted treated samples.

Sweet potato slices dried using NSD had firmness values for control and pre-treated samples of 5.3±0.1 - 97.8±4.6 N. The average firmness values for 3, 5 and 7 mm thickness size were 13.8±2.0, 24.8±3.3 and 48.8±6.6 N, respectively. Sweet potato slices with no pre-treatment had lowest firmness value at 3 mm thickness, while for 5 and 7 mm thickness lemon juice pre-treated samples had lower firmness values followed by control and salted.

The fracturability measured on SPS that were dried using HAD and NSD is shown in Table 2. The results obtained ranged from 23.0±0.5- 112.8±26.1 N for both drying methods. The HAD had fracturability values of 25.1±2.3 - 85.3±7.8 N. The average fracturability values for SPS dried in HAD at 3, 5 and 7 mm thickness size were 28.18±2.4, 52.2±7.5 and 55.5±9.5 N. The NSD dried SPS had mean fracturability values of 23.0±0.5 - 112.8±26.1 N. The average values for fracturability at 3, 5 and 7 mm thickness sizes were 27.4±1.8, 46.8±7.4 and 85.1±18.2 N for control and pre-treated samples.

Texture and fracturability were found to vary among SPS of different thickness sizes and the pre-treatment methods. The results show that as thickness increased, texture and fracturability values also increased in all pre-treatments and drying methods. This shows that thickness size, drying method and pre-treatment had an influence on the final dried product. Lemon juice samples dried using HAD had lower textural values compared to samples with no pre-treatment (control), salted and blanched for samples. Dried samples with small thickness sizes had lower texture values for all pre-treatment methods. This was like findings by Meher and Nayak (2015). There was no significant difference (P>0.05) between the firmness and fracturability values obtained from samples dried using HAD and NSD for the same thickness size and the drying pre-treatment method. Blanched SPS had maximum fracturability in HAD and NSD, this indicates less sensorial tenderness and crunchiness as reported by Caetano et al. (2018).

Color analysis of dried sweet potato slices

Color is one of the most important parameters used to determine the value of the final product and it has a major influence on the buyers' choice (Nisha et al., 2011; Oyebanji et al., 2013). The color evaluation tests results

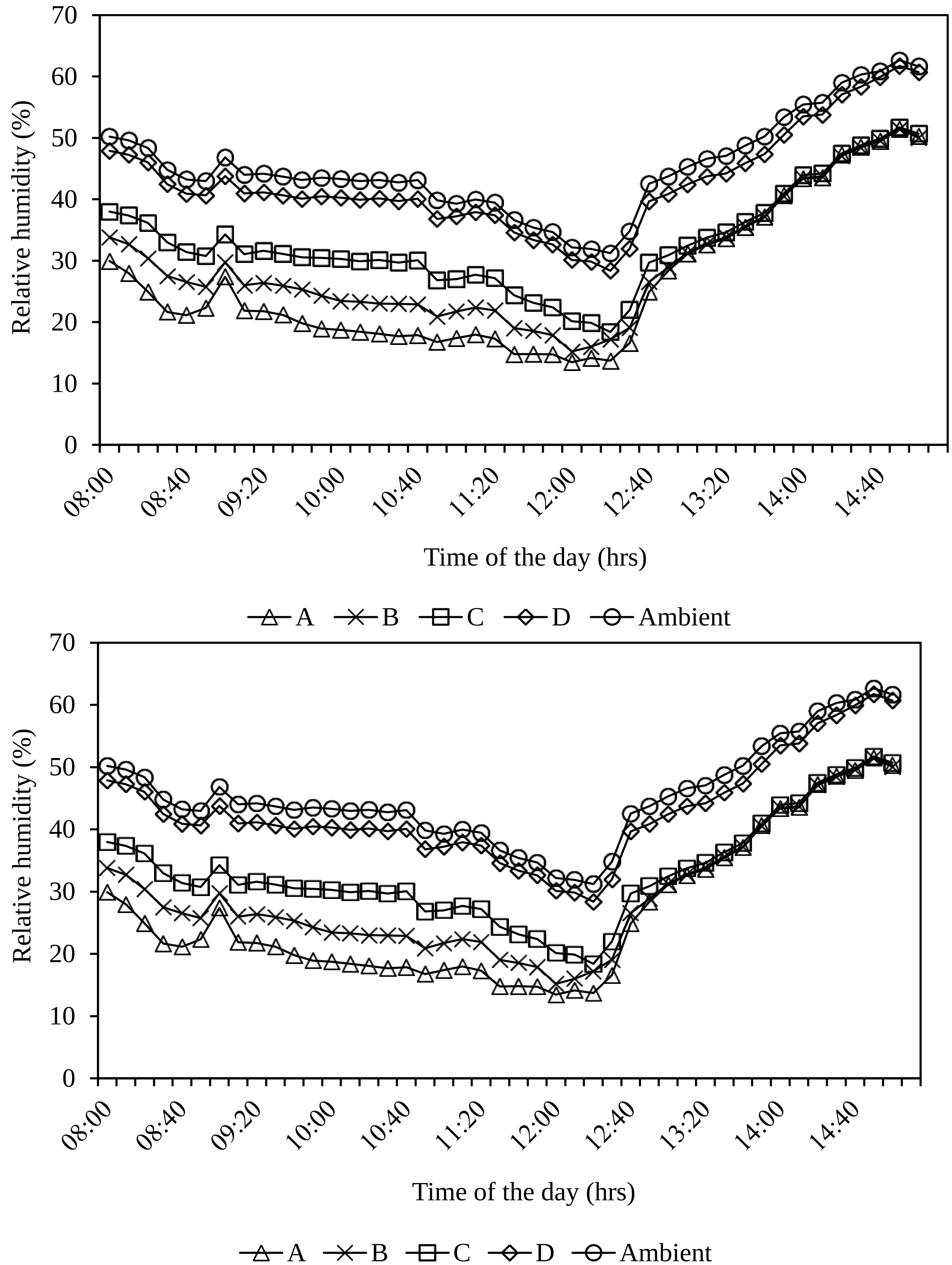

Figure 7. Average daily variation of air relative humidity in an empty dryer (A = exit of the solar collector, B = inlet of the drying chamber, C = center of the drying chamber, D = exit of the drying chamber and Ambient = ambient relative humidity).
Source: Authors

(L*, a* and b*) of SPS dried, using NSD and HAD been

presented in Figures 10 to 12. The final dried SPS were

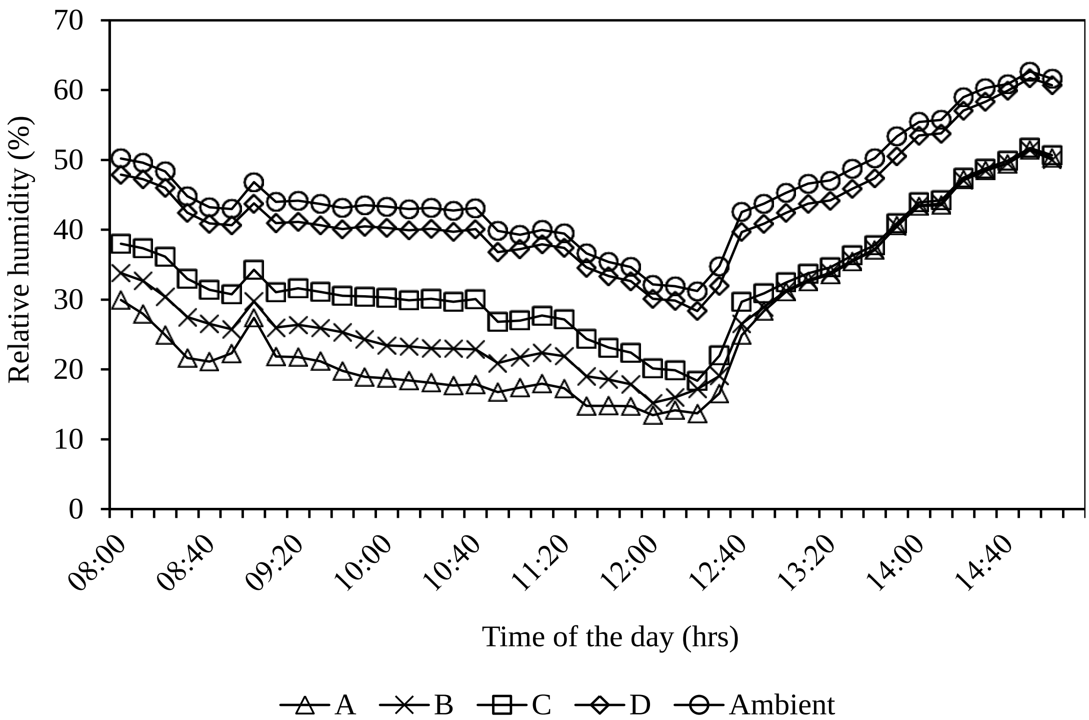

Figure 8. Solar collector performance in a full filling loaded naturally ventilated solar-venturi dryer, (Solar energy [W], Heat gained [W] and Solar radiation [$W.m^{-2}$]).
Source: Authors

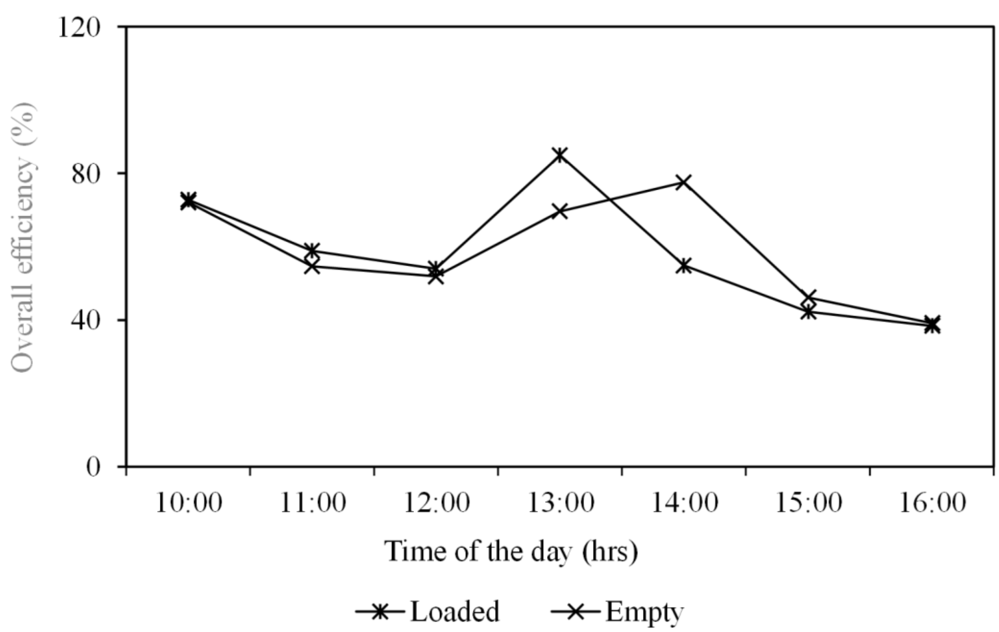

Figure 9. Thermal efficiency of the solar collectors.
Source: Authors

evaluated at a 5% significance level (Xu et al., 2012). It was observed that the SPS dried using NSD had lightness (L*) values of 40.27-75.67, with the control, salted, lemon juice and blanched samples measured to

Table 1. Mean firmness of sweet potato slices dried in a hot-air dryer and a naturally ventilated solar-venturi dryer.

Drying method	Thickness [mm]	Control [N]	Salting [N]	Lemon juice [N]	Blanching [N]
HAD	3	8.8±0.8	11.6±1.0	9.5±0.9	28.0±4.8
	5	26.0±3.2	14.4±4.0	11.4±1.9	34.0±1.2
	7	28.8±4.5	26.7±3.9	15.8±1.2	38.3±3.5
NSD	3	5.3±0.1	10.7±1.8	8.9±2.0	30.3±4.1
	5	23.6±1.0	24.4±5.0	11.4±3.2	39.7±4.0
	7	26.8±9.2	44.0±11.8	26.7±0.9	97.8±4.6

*HAD - hot air oven dryer, NSD – Naturally ventilated solar-venturi dryer, N - Newton, control, lemon juice, salted and blanched – pre-drying treatments for sweet potato slices.
Source: Authors

Table 2. Mean fracturability of dried sweet potato slices.

Drying method	Thickness [mm]	Control [N]	Salting [N]	Lemon juice [N]	Blanching [N]
HAD	3	26.9±3.7	25.8±2.0	25.1±2.3	34.9±2.6
	5	57.9±13.3	34.1±7.6	31.4±1.1	85.3±7.8
	7	60.7±7.6	55.5±7.0	39.9±3.5	65.8±19.9
NSD	3	25.4±3.1	24.7±1.7	23.0±0.5	35.3±1.7
	5	42.5±2.3	57.2±9.3	31.9±6.2	55.5±11.7
	7	64.1±20.6	101.4±19.7	62.1±6.3	112.8±26.1

*HAD - hot-air oven dryer, NSD - Naturally ventilated solar-venturi dryer, N= Newton, control, lemon juice, salted and blanched – pre-drying treatments for sweet potato slices, mean values (±SD).
Source: Authors

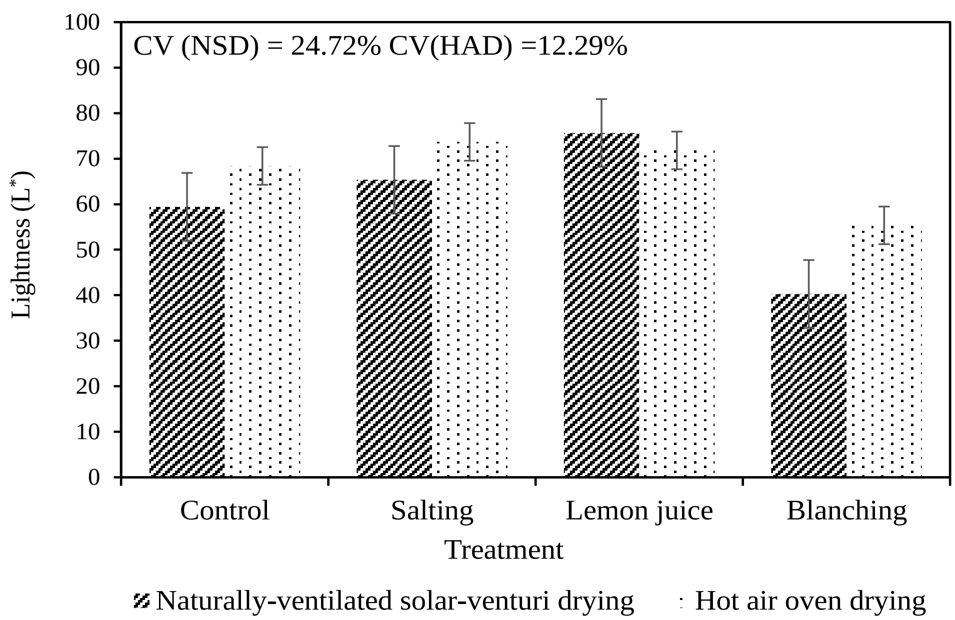

Figure 10. Variation of lightness in sweet potato slices dried using NSD and HAD (*CV = coefficient of variation, NSD = Naturally ventilated solar-venturi dryer and HAD = hot air oven dryer).
Source: Authors

be 59.41, 65.35, 75.67 and 40.27, respectively as shown in Figure 10. The yellowness of these samples was

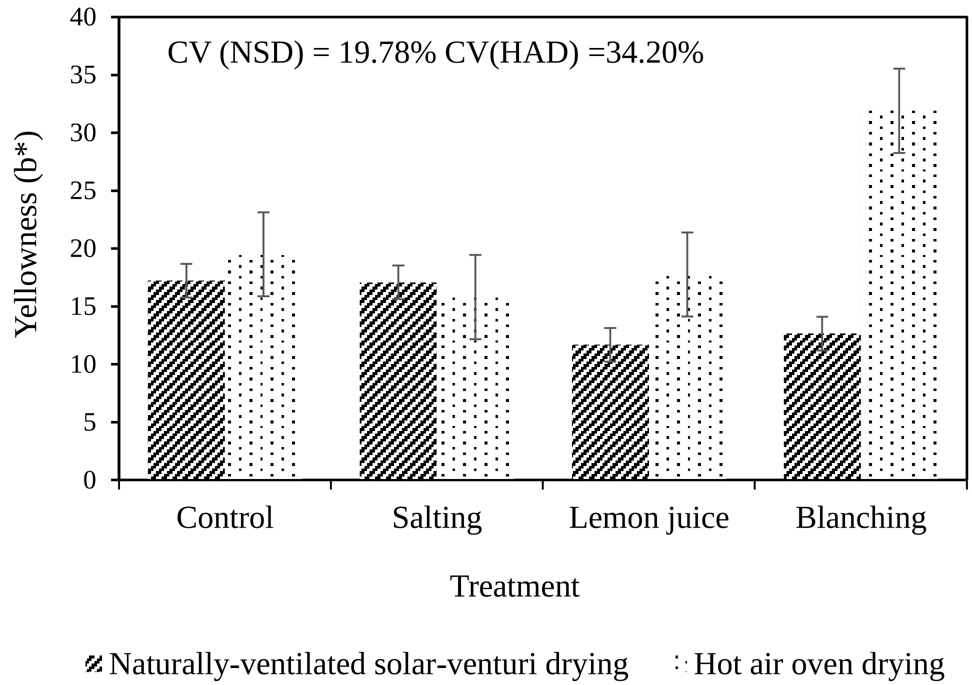

Figure 11. Variation of yellowness in sweet potato slices dried using NSD and HAD (CV = coefficient of variation, NSD = Naturally ventilated solar-venturi dryer and HAD = hot-air oven dryer).
Source: Authors

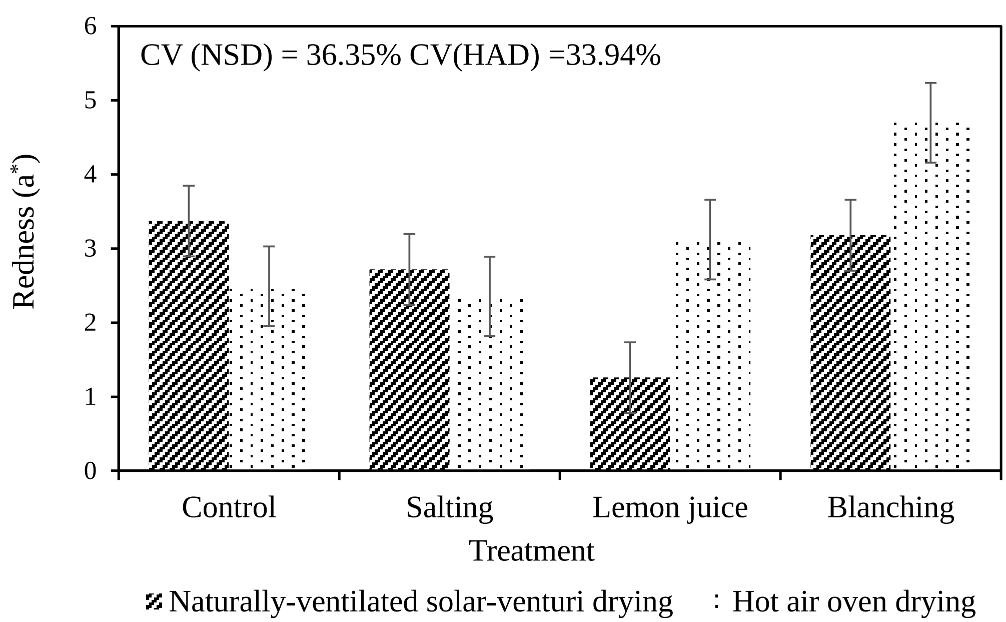

Figure 12. Variation of redness in sweet potato slices dried using NSD and HAD (CV = coefficient of variation, NSD = Naturally ventilated solar-venturi dryer and HAD = hot air oven dryer).
Source: Authors

measured to be 17.23 (control), 17.09 (salted), 11.70 (lemon juice) and 12.67 (blanched), as shown in Figure 11, respectively. The Redness (a*) values were measured to be 3.37, 2.72, 1.26 and 3.18 for control, salted, lemon juice and blanched samples, respectively as shown in Figure 12. The average lightness, redness and

Table 3. Mean hue angle measured on sweet potato slices dried in a solar-venturi dryer and hot air oven dryer.

Treatment	HAD [°]	NSD [°]
Control	82.7[a]	78.9[a]
Salted	81.5[a]	81.0[a]
Lemon juice	80.0[a]	83.9[b]
Blanched	81.6[a]	75.9[a]
CV [%]	1.4	4.20

'*HAD – hot-air oven dryer, NSD – Naturally ventilated solar-venturi dryer. Means with the same latter in the column do not differ from each other tested at 5% level of significance, CV – coefficient of variation.
Source: Authors

yellowness were calculated to be 60.18, 2.63 and 14.67, respectively. Redness and yellowness values were 1.26 - 3.37 and 11.70 - 17.23, respectively. The coefficient of variation (CV) for lightness, redness, and yellowness in a NSD was 24.72, 36.35 and 19.78 %, respectively.

The SPS samples dried in HAD had lightness values of 55.36 and 73.70, with the control, salted, lemon juice and blanched samples measured to be 68.39, 73.70, 71.82 and 55.36, respectively as shown in Figure 10. The redness values ranged from 2.35 - 4.70, with control, salted, lemon juice and blanched samples measuring 2.49, 2.35, 3.12 and 4.70, respectively. The yellowness was measured to be 19.51 (control), 15.81 (salted), 17.76 (lemon juice) and 31.91 (blanched). The (CV) for lightness, redness and yellowness were measured to be 12.29, 33.94 and 34.20%, respectively. The average of all color indicators in the HAD (lightness, redness, and yellowness) were measured to be 67.32, 3.17 and 21.25, respectively.

The treatment and drying methods were observed to have an influence on the quality of the final dried product. Hot air oven drying had better final dried sweet potato chips, in terms of color and lightness compared to NSD. All SPS dried in HAD were bright in color (L* >50). This is like to findings by Odenigbo et al. (2012) who observed L* above 50. This was a result of the higher drying temperature and the shorter drying time, which inhibited change in color of SPS. Blanched SPS had minimal lightness values for both drying methods and treatments. This indicates that blanching did not improve the color of the dried samples. Sweet potato samples dried in NSD were dried in a slightly lower temperature; hence there was a longer drying time which may have allowed change in surface characteristics of the samples thus a change in color. It was observed that there was no significant difference (P<0.05) on the lightness of the SPS dried, using HAD. This resulted from a high temperature and a shorter drying time. The redness (a*) of dried SPS was not significantly different (P<0.05). NSD-dried SPS had a higher redness, as compared to HAD, which was evident by the browning and yellowness of the final dried products that was observed on the hue angle (Odenigbo et al., 2012). This would be a result of polyphenol oxidase activity which allowed enzymatic browning in low temperature drying.

The hue angle for dried SPS was 80.0 – 82.7° for a HAD and 75.9 to 83.9° for NSD, as shown in Table 3. The calculated mean hue angle was 82.7, 81.5, 80.0 and 81.6° for the control, salted, lemon juice and blanched samples in a HAD, respectively. Samples dried under NSD had 78.9, 81.0, 83.9 and 75.9° mean hue angle values, respectively. Sweet potato slices dried in HAD and NSD had a hue angle of 80.0 – 82.7° and NSD 75.9° – 83.9°, respectively. Studies have shown that the hue angle has a great influence on the yellowness of the drying food material, which was reported by the findings of Caetano et al. (2018).

Conclusion

Solar venturi drying was evaluated to illustrate its performance when loaded with sweet potato samples and empty under Pietermaritzburg conditions. It was concluded that during the day, the increase in ambient temperature increases the naturally ventilated solar-venturi dryers' temperature when loaded with samples and when empty (unloaded). It was also observed that there is a positive strong relationship between ambient and the solar-venturi temperatures. Increasing temperature reduces ambient RH, which results in a decrease of the RH inside the NSD. As ambient temperature dropped, ambient RH increased and the temperature inside the NSD decreased which resulted in an increase in RH inside the dryer. Hence, the RH increased at night when the temperature dropped and when there is no solar radiation, which requires that the drying samples be removed from the dryer at night and kept in airtight containers. This study has identified a need for investigating an innovative naturally ventilated solar-venturi dryer (NSD) that uses solar energy to preserve sweet potato slices (SPS) and to reduce the post-harvest losses experienced by the smallholder farmers in South Africa. Considering that most of South African provinces receive an average of 5.5 $kWh.m^2$ of solar irradiation, the use of solar energy, as a source of energy is feasible in the country. Pietermaritzburg (temperature, RH and solar radiation) do allow the adoption of the NSD; however, there is still a need to find ways increase airflow velocity in order to reduce the drying time and optimizing the dryer to maintain low RH during day light and at night.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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