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EFFECTS OF RELATIVE HUMIDITY AND TEMPERATURE ON SMALL SCALE PEACH FRUIT DRYING USING A TUNNEL SOLAR DRYER: A CASE STUDY OF PEACH FRUIT PRODUCED BY SMALL SCALE FARMERS IN THE MIDLANDS OF KWAZULU-NATAL, SOUTH AFRICA.

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ABSTRACT

The study investigated the relationships between tunnel and ambient temperature and relative humidity (RH) and their effects on the performance of a tunnel solar dryer tested by drying peach slices. The temperature and RH showed an inverse proportion because if the ambient temperature increased, both the tunnel and ambient RH dropped. There was a direct proportion between the increasing ambient temperature and increased tunnel temperature. The use of treatment such as ascorbic acid or lemon juice did not have a significant effect on the overall drying between the yellow and white landraces. Ascorbic acid had a tendency to perform better than lemon juice which was also better than the untreated slices in terms of the taste and overall acceptability of the dried products. White peach slices were of better quality than yellow slices. It was concluded that solar drying is possible in the Midlands region. Extension officers and researchers can work hand in hand in partnerships with communities in implementing old and cheap but ignored technologies such as this method of food drying.

Keywords: Ambient temperature, ambient RH, tunnel RH, tunnel temperature, lemon juice, ascorbic acid.

1. INTRODUCTION

Extension services and researchers working in the Impendle area of rural KwaZulu-Natal mist belt in South Africa are well aware that peaches are seen all over the area, whereby almost every homestead has one or up to 30 trees which have long been an important source of nutrition for the mostly impoverished households in this traditional authority area (Phillips, 2015). However, peaches are not grown only in Impendle, since areas of Tugela Region and Kokstad also produce this fruit in the small-scale sector. Small scale peach growers in the province of KwaZulu-Natal lose a significant portion of their fruit because they lack the capacity and resources to harvest and use or process all the fruit which is produced within a short two and half months harvesting season (Phillips, 2015). Pests and diseases are always a problem in the small-scale farming sector where there are limitations of proper crop husbandry skills (Phillips, 2013; Phillips, 2015). Chemicals are also scarce or an expense (Phillips, 2013; Phillips, 2015). It becomes a challenge to the extensionist when farmers bring their difficulties such as the lack of storage facilities or that the fruit becomes spoilt. Farmers tend to leave the

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fruit hanging on the tree even during ripening stages. This results in over-ripening, pests and diseases attacking, and the fruits dropping off the tree, losing their value. It is estimated that about 50% of food is lost by Sub-Saharan African farmers during postharvest due to a lack of storage facilities (Gunders, 2012). Ayua *et al.* (2016) reported that the reduction of postharvest losses in fruit and vegetables is important to ensure food security and availability now, and in the future. Kader and Rolle (2004) had earlier reported that there is less funding for research projects geared towards reducing food losses, especially in the developing countries. Mustayen, Mekhilef & Saidur (2014) explained that the quality and quantity of many agricultural food products, such as fruits, grains and vegetables are often low because of poor processing techniques and lack of storage facilities.

Drying of agricultural products has always been considered to be an important technique of conserving agricultural commodities. Drying is defined as the process of moisture removal by simultaneous heat and mass transfer (El-Sebii & Shalaby, 2012). Open sun drying has been widely used in developing countries, because mechanical dryers are expensive, unaffordable and also require fuel to operate (El-Sebii & Shalaby, 2012). Food drying depends on a number of weather parameters. It has been reported that the most important weather parameters are RH, temperature and wind speed for evapotranspiration models (Valipour, 2014). Pangavhane, Sawheny & Sarsavadia (2002) explained that open sun drying food under unfavourable misty and cool climatic conditions such as the similar conditions in the Midlands of KwaZulu-Natal leads to severe losses in the quality and quantity of dried products.

The introduction of solar dryers especially in areas with high RH is therefore one of the solutions to reduce crop losses and improve quality of dried products (Yaldiz, Erteken & Uzun, 2001). In artificial solar food drying with improved dried product quality as opposed to open sun drying, air velocity and temperature are very important parameters (Banout *et al.*, 2011). Furthermore, mass transfer of air and evaporation of water are a result of high heat energy during evaporation, which are some of the drying condition requirements that play an important role in ensuring that the product is dried effectively (Jain & Tiwari, 2004). Tunnel solar drying is one of the methods currently used by developing nations to protect and improve the quality of their dried agricultural products. Zomorodian, Zare & Ghasemkhani (2007) described tunnel drying as the absorption of solar radiation into the chamber resulting in crop temperature increasing and discharging long wave length radiation as the main working phenomena of the dryer. However, these authors further reported that although the temperature in the chamber may increase above that of the crop, the main limitation is moisture compressing inside the drying chamber. There is therefore a relationship between the weather parameters and drying conditions required in a solar tunnel dryer. An imbalance between the two environments may result in improper food drying. During the solar drying period, maximum solar radiation, maximum efficacy and minimum ambient moisture content should always be considered. According to an explanation by Jain and Tiwari (2004), drying a product enclosed in a plastic covering produces a greenhouse effect to trap the solar energy. However, the rate of drying (moisture evaporation) depends on various external parameters. Solar radiation, ambient temperature, wind velocity and RH, as explained by Valipour (2015), are some of the parameters. Instead of sun or shade drying, solar drying provides a better quality product and is classified into four categories (Table 1) according to the mechanism by which the energy used to remove moisture is transferred to the product (El-Sebaii & Shalaby, 2012). When the product being dried is stored under shelter during the night and being subjected to high moisture content or rain it can be remoistened. This will result in considerable spoilage that includes enzymatic reaction, growth of micro-organisms, and augmentation of mycotoxin which causes reduction in product quality (Mustayen *et al.*, 2014). There are specific requirements that properly designed solar drying systems such as tunnel dryers must take into account before drying specific crops (Gurlek, Özbalta & Gungor, 2009). These requirements include thickness of the product dried, season of drying and weather conditions. In order for the product to be dried, the ambient RH, which is weather dependant, must be lower than the moisture content of the product to be dried in a tunnel using solar energy.

Mustayen *et al.* (2014) described tunnel solar drying as the most effective in terms of low costs, maintenance and operation, however, these authors further explained that this type of drying has some limitations.

2. PROBLEM STATEMENT AND STUDY AIMS

Agricultural researchers are mainly focusing on production, be it meat, fruit or vegetables. After several visits to Impendle, it was clear that farmers lose their produce. The Extension Services Office also approached the research team while attending farmers in the field, to come together and curb such fruit losses. This was brought on due to significant losses of peach fruit, a lack of processing techniques and facilities of the fruit in KwaZulu-Natal Midlands, and the fact that open sun drying may not always be a possibility due to unpredictable weather conditions and high moisture content.

The aim of this study was to investigate drying conditions in season one and test whether or not tunnel solar dryer could be used to dry peach fruit during season two of the study in the mist belt of the Midlands in KwaZulu-Natal. However, drying is not only limited to peaches, but other food commodities including vegetables, mushrooms and other fruit types available in the region and can be dried using solar energy.

3. OBJECTIVES OF THE STUDY

In season one, all data parameters were collected concurrently using the local weather station of the Agricultural Research Council to determine ambient data. HOBO data loggers were used to determine tunnel data. In season two, the data collected in season one was repeated and peach slice drying data was also collected.

3.1. Season One

Objective 1: To obtain and compare data on ambient temperature and RH.
Objective 2: To obtain and compare data on tunnel temperature and RH.
Objective 3: To compare ambient and tunnel relationships in terms of RH and temperature.

Table 1: Description of four solar drying methods (El-Sebaii & Shalaby, 2012)

Category of dryer	**Description**
Sun or natural dryer	The material to be dried is placed directly under hostile climate conditions like solar radiation, ambient air temperature, RH and wind speed to achieve drying.
Direct solar dryers	The material to be dried is placed in an enclosure, with transparent covers or side panels. Heat is generated by absorption of solar radiation on the product itself as well as the internal surfaces of the drying chamber. This heat evaporates the moisture from the drying product and promotes the natural circulation of drying air.
Indirect solar dryers	Air is first heated in a solar air heater and then ducted to the drying chamber.
Mixed-type solar dryers	The combined action of the solar radiation incident directly on the material to be dried and the air pre-heated in the solar air heater furnishes the energy required for the drying process.

3.2. Season Two

Objective 1: To obtain data on ambient temperature and RH.
Objective 2: To obtain data on tunnel temperature and RH.
Objective 3: To dry white and yellow peach fruit slices with three treatments (untreated, lemon juice and ascorbic acid treatments) and monitor the drying patterns.
Objective 4: To perform taste testing with a trained panellist to determine product quality and acceptability.

4. PURPOSE

To test effects of relative humidity and temperature on tunnel solar drying.

5. MATERIALS AND METHODS

The study was conducted over a two-year period in 2014/2015 (Season One) and 2015/2016 (Season Two) from December to March for each period. The Research Station is located at 30°16'E, 29°32'S and 1130 m above sea level.

5.1. Experimental design

One tunnel dryer x 2 peach cultivars (white and yellow peaches) x 3 pre-treatments replicated three times (lemon juice, ascorbic acid and control) x 2 seasons.

5.1.1. Season One: 2014/2015

A parabolic solar tunnel dryer was installed at Cedara Research Station in the mist belt of KwaZulu-Natal, South Africa, with doors facing north and the back facing south. A transparent 200-micron plastic sheet was used to cover the tunnel. The tunnel dimensions were as follows: length (l) - 7 m; breadth (b) - 2.95 m; height (h) - 2.65 m; door size - 0.6 m (w) x 2.35 m (h); triangular ventilation at the top of the door, base - 2.1 m and height is 0.6 m. Wind speed averaged at 0.8 m/s, and the floor was covered with black plastic sheet. The wire was used to make tray supports on the sides of the tunnel, to place loaded trays on during the drying process. In the middle of the tunnel, a passage stretched from the door to the back of the tunnel. On top of the door, a curtain was opened and placed on the tunnel roof during drying which allowed wet and warm air to escape the tunnel. The back vent would allow dry air to enter the tunnel through the 0.9 m^2 air vent opening. The total drying area of the tunnel was 21 m^2. Racks of 0.30 m x 0.60 m food grade nets were constructed and used to dry peach slices.

Tunnel temperature and RH were determined using four HOBO Pro v2 onset data loggers installed in a tunnel and were moved around to different locations of the tunnel to determine any variation in temperature and RH (Nishizaki & Carrington, 2014). In order to determine ambient temperature and RH, a Campbell Scientific CR10 Data Logger (Gush, 2008) installed in the local weather station was used.

5.1.2. Season Two: 2015/2016

The aim of season two was to test the tunnel dryer and dry peach fruit while monitoring all the parameters that were recorded in season one of the study. White and yellow peach landraces were handpicked at Impendle in KwaZulu-Natal, South Africa. After harvesting, diseased, spotted and bruised fruit were removed, and the remainder were stored overnight in a cold room with temperature and RH settings at 5°C and 85% respectively in order to acclimatise the fruit physiology and because drying could not be started in the afternoon. On the following day, fruit were removed from the cold room and allowed to reach room temperature before processing took place.

6. RESULTS AND DISCUSSION

6.1. Season One

The variation of ambient temperature from 08:00 AM to 19:00 PM significantly affects the tunnel temperature positively (Figure 1). The increasing ambient temperature results in an increase in the tunnel temperature, however, the tunnel temperature remains higher than the ambient temperature. A similar relationship is observed from 20:00 PM to 07:00 AM whereby ambient temperature decreases, followed by a decrease in tunnel temperature. However, the tunnel temperature still remains higher that the ambient temperature during night time. At about 05:00 AM, the ambient temperature starts to increase, and the tunnel temperature also increases.

The ambient and tunnel RH (Figure 1) also appeared to be dependent on temperature. The increasing ambient temperature causes a decrease in ambient RH accompanied by a sharp decrease in the tunnel RH. In addition, the ambient RH was always higher than the tunnel RH. It is clear that the days have higher tunnel temperatures reaching 45°C, and RH above 40%, whereas the nights have higher ambient RH close to 100% and low ambient temperatures nearing 15°C.

Janjai, Intawee, Kaewkiew, Sritus & Khamvongsa (2011) reported their study findings that the lowest RH in the tunnel is during midday. The current study shows the same evidence of the lowest tunnel RH at 13:00 PM, during the day. The difference is that 40% is the lowest RH, which is still very high for food drying. When the tunnel temperatures drop below 20°C during the night, the RH in the tunnel increases above 90%. Drying has been possible in tunnel dryers with RH above 40%. Stiling *et al.* (2012) were able to dry fruit below 10% RH in the solar dryer and ambient RH above 20%.

Kaewkiew, Nabnean and Janjai (2012) found that the RH inside the dryer was below the ambient RH and the current study findings were congruent with what these authors found in their study. Zomorodian *et al.* (2007) as well as Ramos, Miranda, Brandao and Silva (2010) explained that solar drying rate depends on the surrounding moisture content and temperature. The driving force of water diffusivity is the balance between the water content in each instance and the equilibrium water content. The moisture content of the product being dried should be higher than that of the surrounding environment. The drying rate decreases as the RH increases in the surrounding environment at a constant temperature and increases at an increasing temperature and constant RH (Inazu, Iwasaki & Furuta, 2002). Ramos, Brandao & Silva (2015) were able to successfully develop a simulation model by drying grapes daily with RH reaching below 10% during the day and remained below 80% during the night, and average maximum daily temperature of 40 °C and a minimum of 15 °C. Fudholi *et al.* (2014) successfully dried chilli in a small 2.4 m x 1.0 m x 0.6 m drying chambers with drying chamber temperature and RH ranging from 28°C to 55°C and 18% to 74%.

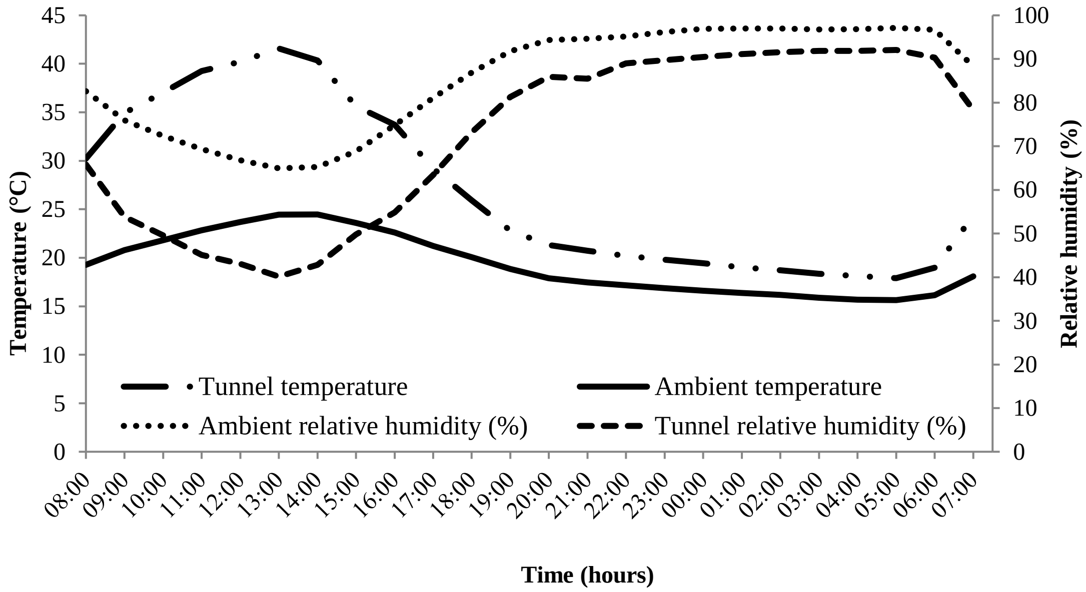

Figure 1: The relationship of ambient and tunnel temperature and RH mean data collected over a four-week period

Kaewkiew *et al*. (2012) found that the RH of the chilli was reduced to 9% in three days and this was possible because the RH of the moisture outside the tunnel was lower than that in the tunnel. Manaa, Younsi & Moummi (2013) concluded that the water content of the dried product was affected by several parameters including temperature of the air, speed of the air, thickness of the product and pre-treatment, as well as the fact that increasing the temperature of the drying air and reducing the thickness of the tomato slice reduces the drying time.

The positive relationship between higher drying chamber temperature and lower ambient temperature are related to what the current study found (Figure 2 A). When the ambient temperature increases, tunnel temperature also increases, with the relationship strong and positive. The drying tunnel RH was also related to ambient temperature (Figure 2 B). When the ambient temperature increases, there was a decrease in tunnel RH. The limitation in the current study was that the average lowest day tunnel RH was >40% and this was too high for drying and may result in slow drying rate and spoilage of the product being dried. However, the relationship trends are similar to the environmental conditions able to dry food successfully. The maximum average night RH was above 90% and this may result in remoistening and spoilage of the product being dried at night, and therefore, extra precautions are mandatory and must be in place before drying in the region where the study was conducted. The rainfall and mist have an impact on such high moisture content in the region. Ambient RH is also related to ambient temperature, since when the ambient temperature increases, there is a decline in ambient RH (Figure 2 C). The saturation of ambient air with high RH strongly affects the tunnel RH as it also increases (Figure 2 D).

Khiari, Mihoubi, Mabrouk & Sassi (2004) reported that an optimum temperature for food water removal is 80°C and if higher temperatures are used, the food will cook instead of drying. These researchers also found that low humidity assists the drying process since food contains a lot of water and if the surrounding environment is humid, the drying rate is reduced, and increasing air flow may improve the drying process. The current study temperature remained below 80°C, implying that drying is still possible below 80°C, however, the time to complete drying may be extended with a day and a few hours.

The close relationship between ambient and tunnel solar dryer temperature and RH is very important. Manaa *et al.* (2013) found while drying tomato that cultivars also affect the drying conditions and quality of the dried product when the temperature is above 40°C. However, when the temperature was below 40°C, the drying curves and product quality were similar.

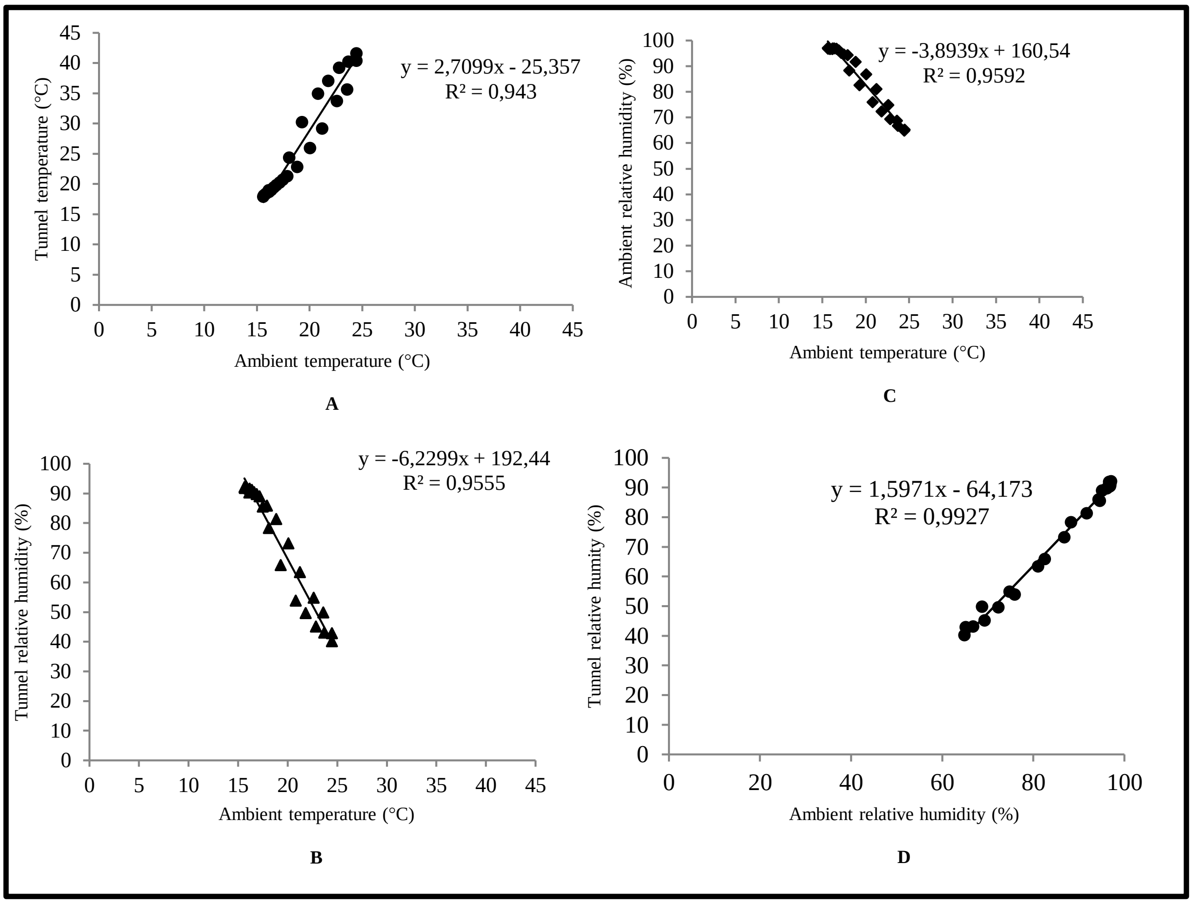

Figure 2: The relationship between (A) ambient and tunnel temperatures, (B) ambient temperature and tunnel RH, (C) ambient temperature and ambient RH, and (D) ambient RH and tunnel RH.

6.2. Season Two

Figure 3 displays the drying characteristic curves of lemon juice or ascorbic acid pre-treatments and an untreated control of the white and yellow peach slices used for this study. The drying of peach slices began at the same time with an average moisture between 80 and 85% ($p > 0.05$). There was a significant sharp drop during the first six hours for white control and yellow ascorbic acid slices ($p < 0.05$). However, the white lemon treated and white untreated had a significant drop in the first six hours, whereas white lemon, white ascorbic, yellow lemon, and yellow untreated were not significantly different in the first six hours ($p > 0.05$). The yellow ascorbic acid treated slices' average was the least in the decreasing moisture content for the first six hours. It also started as the highest moisture content at 85%, however, it was not significantly different from all other treatments. The yellow control and the white ascorbic acid treatment followed similar trends from the 0 hour to the 22nd hour of drying ($p > 0.05$). Except for the yellow control and white ascorbic acid, all treatments were significantly different during the 8th hour of drying.

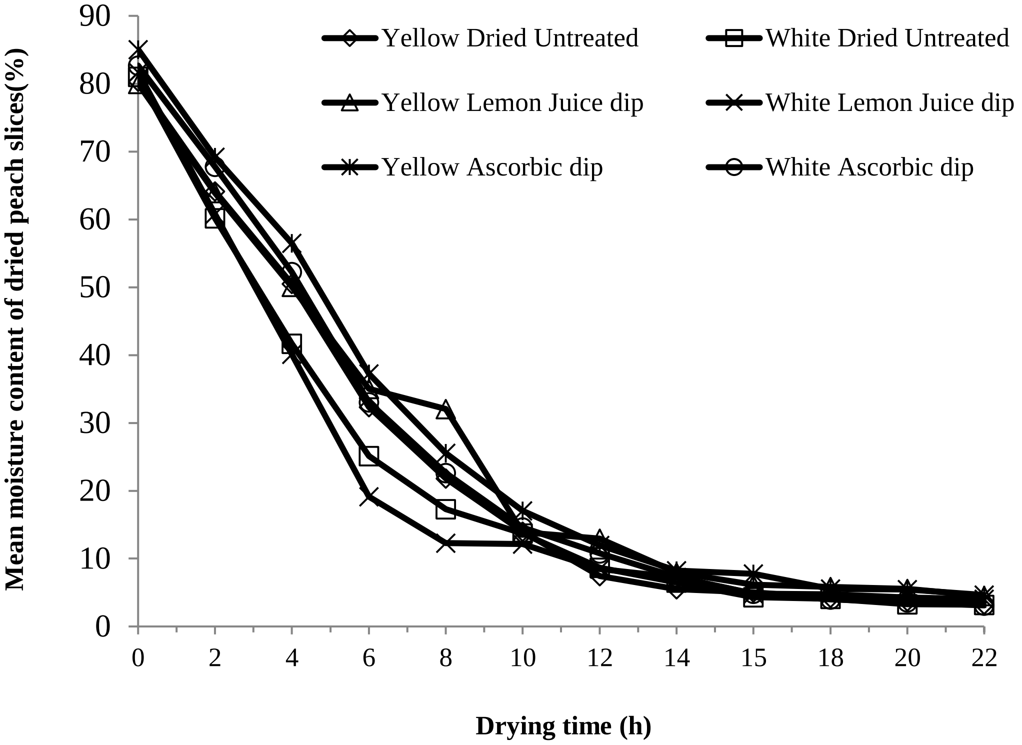

Figure 3: Drying characteristic curves of different pre-treated and untreated peach slices

Moreover, there were no significant differences from the 10th hour to the 22nd hour of drying. The drying process was completed at 6% moisture content. From the 18th hour to the last drying hour, there was no change in peach mass. White lemon and the yellow lemon treatments showed a strong significant difference in the drying times ($p < 0.001$). It is evident in figure 3 that white peach dried much quicker than yellow. The white lemon dipped slices dried at the fasted rate in the first six hours. The white untreated slices also dried faster in the first six hours. However, the yellow cultivar (treated or non-treated fruit) did not show any trend and remained inconclusive in the drying curves.

Furthermore, figure 4 displays the results of nine hedonic scales obtained from a taste testing conducted by 15 trained panellists a day after drying the fruit.

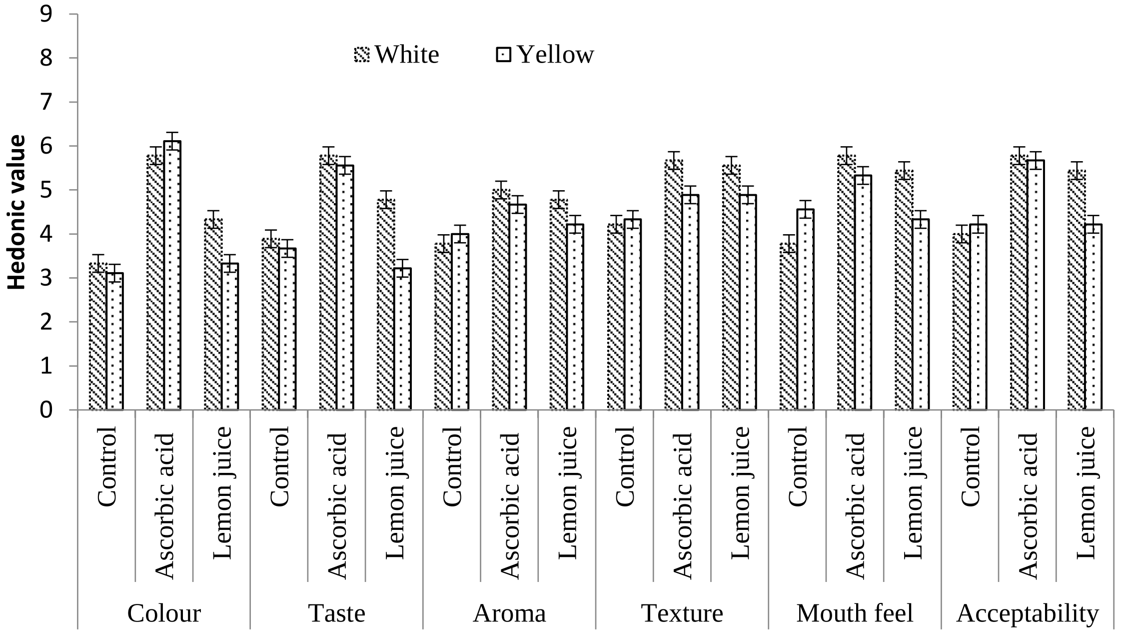

Figure 4: Nine-point hedonic scale obtained from taste testing panellists

(i) *Colour:* Both controls of white and yellow cultivars turned brown during the processing and drying period and hence they scored lowest in colour rating, followed by lemon juice. Ascorbic acid was significantly different from both lemon and untreated peach for both yellow and white cultivars. However, there was no significant difference between white and yellow slices in the ascorbic acid treatment. Ascorbic acid was above average and received a score of about 6/9 for both cultivars.

(ii) *Taste:* Ascorbic acid received the highest score also in the taste. However, the control of white peach displayed better taste scores than lemon juice treatment in yellow cultivar. White cultivar treated with lemon was significantly better from both ascorbic acid and control for both yellow and white cultivars.

(iii) *Aroma:* Ascorbic acid had no significant difference between the white and yellow cultivars. White slices treated with lemon was significantly better than yellow slices treated with lemon. Ascorbic acid had a tendency to produce better aroma as it did with colour and taste.

(iv) *Texture:* Peach slices treated with ascorbic acid and lemon treatments in both yellow and white cultivars were significantly different, with white produced a higher score for better texture. In addition, white slices were ranked higher than yellow in texture for the lemon treatment. The white slices were rated significantly higher than the control and lemon for both white and yellow cultivars.

(v) *Mouth feel:* The white slices of ascorbic acid and lemon treatments were rated with the highest scores for better mouth feel than the control for both white and yellow cultivars and were also rated higher than ascorbic acid and lemon for the yellow cultivar. However, white slices of ascorbic acid were also rated significantly higher than white slices of lemon juice.

(vi) *Overall acceptability:* The white and yellow slices with ascorbic acid were not significantly different but were rated the highest for better acceptability. The lemon juice white slices were not significantly different from ascorbic acid treatments applied

in both yellow and white peach slices. The lemon juice treatment in yellow peach was not significantly different from the control of both white and yellow peach slices.

7. CONCLUSION

Extension and advisory service, together with researchers and small-scale farmers, can implement a project like this one. It was concluded that during the day, the increase in ambient temperature increases the tunnel temperature. There is a strong and positive relationship between ambient and tunnel temperatures. Increasing temperature reduces the ambient RH, which is associated with a decrease of the RH in the tunnel dryer. At night, the moisture content in the tunnel increases to very high and unacceptable levels. Farmers who adopt the technology must remove the drying product and keep it sealed in airtight containers or bags overnight. There was not much effect by the use of lemon juice, ascorbic acid or no treatment on the drying rate of both yellow and white slices. The white cultivar performed much better than the yellow cultivar when it comes to taste testing. The ascorbic acid produced better slices than lemon juice. The study further concluded that the drying conditions do allow the use of tunnel solar dryer in the Midlands of KwaZulu-Natal with a caution that produce needs to be removed overnight and be stored in airtight containers or plastic bags.

8. RECOMMENDATIONS

It is recommended that farmers utilise the inexpensive solar dryers in the midlands of KwaZulu-Natal Province since drying was a possibility in the mist belt, which was regarded as the worst-case scenario. It is important to consider the period of drying. Between December and March, there are rains in the Midlands and mist, however, close monitoring weather patterns does allow drying to take place. A farmer would need at least three to four days of no rain, depending on the slice thickness of their produce. Slices thinner than 4 mm shrink and change to black colour. It is therefore recommended to use peach quarters or slices thicker than 5 mm. Remove the product being dried at night to avoid rewetting, which causes grey mould during the drying period if the product was not removed. This work stresses that farmers need to have a clear problem before they can accept and implement some of the research output.

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