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Effect of refractance window drying (RWD) and low temperature low humidity (LTLH) drying on the physical, nutritional and functional characteristics of pineapple slices

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Abstract
Pineapple is a seasonal fruit cultivated in the tropical regions. The post-harvest losses of pineapple can be reduced by improving the shelf-life through different drying technologies. Two novel technologies namely, refractance window (RW) drying and low temperature low humidity (LTLH) drying have been employed in this study. The influence of process variables like temperature and relative humidity on the quality characteristics of pineapple was studied by conducting RW drying at 80 °C & 90 °C and LTLH drying at 10% and 20% relative humidity at constant temperature of (35 °C). Both the drying techniques have proven to be effective and RW drying retained nutritional and chemical properties better than LTLH drying, which creates a scope for utilizing RW dryer in different sectors of food processing.

Keywords: refractance window, LTLH, pineapple, physico-chemical, drying

1. Introduction

Pineapple (*Ananas comosus*) belongs to the family *Bromeliaceae*, originating from South America. It is identified to be the third most commercially important tropical fruit globally. The common pineapple varieties include Giant Kew, Queen, Red Spanish, MD2 and Morris. (Sun *et al*., 2015) [50]. Costa Rica, Philippines, Brazil, Indonesia, China and India are some top producers of pineapple in the world (*FAOSTAT*, 2019) [16]. The nutritional composition of pineapple includes carbohydrates (dietary fiber and sugars), vitamins (B1, B3, C), minerals (Ca, Mg, P, K, Na) and water. The physicochemical properties like colour, firmness, moisture content, pH and Total Soluble Solids (TSS) play a conspicuous role in determining the characteristics of the varieties (Ancos *et al*., 2016) [5]. The aroma and flavour profiles also substantiate the ability of pineapple to be used as functional foods (Mohd Ali *et al*., 2020) [31]. Bromelain, a proteolytic enzyme which helps in improving digestion, is exclusively found in pineapple as stem bromelain (EC 3.4.22.32) and fruit bromelain (EC 3.4.22.33). Besides possessing anti-cancerous, anti-inflammatory, antioxidant and therapeutic properties, it also supports in improving drug (antibiotics) absorption (Wijeratnam, 2015) [56].

Drying is a traditional practice adopted worldwide to extend the shelf-life of foods. Dehydrated foods have lower water activity, are convenient to handle during transportation and storage due to reduced volume. Convective drying is commonly adopted in food industries but has its own limitations wherein a product with significant nutrition loss is rendered (Orrego *et al*., 2014) [37]. Despite the modern life-style urging the humankind to opt for processed foods, increasing consumer awareness on clean label ingredients and high-quality nutrimental foods has emerged (Ciurzyńska *et al*., 2019) [12]. Based on technological advancements, the four generations of dryers include cabinet dryer, spray and drum dryer, freeze dryer, and Refractance Window Dryer (RWD) and Low Temperature Low Humidity (LTLH) dryer (Vega-Mercado *et al*., 2001) [54]. Freeze-dried products have the highest retention of nutritional and organoleptic properties when compared to its counterparts. Besides high energy demand, the operational and maintenance cost of the dryer is eightfold than that of a conventional dryer (Duan *et al*., 2016) [15]. This major drawback confines its use to high-value products and therefore induces the need for comparable alternative technologies.

Refractance Window drying is an emerging technology wherein the product to be dried is placed on a transparent polyester film which floats on a water bath containing hot water. The process takes place at atmospheric pressure and heat transfer occurs by conduction, convection and radiation. At initial drying rates, due to the decrease in refraction at the plastic film, infrared energy is emitted and this is absorbed by the product moisture, which results in rapid drying. Eventually, as the moisture decreases, the infrared window closes and drying takes place by conduction. Since the heat transfer is mediated by the polyester film, the product temperature is less than that of the hot water temperature (Mahanti *et al*., 2021) [26]. With 52-77% thermal efficiency over conventional dryers, RWD has scope for low-cost drying (Raghavi *et al*., 2018). Studies undertaken with juices, purees, pulps, fruit slices and also probiotics have explored the applications of RWD (Abonyi *et al*., 2002; Cichella Frabetti *et al*., 2018; Jafari *et al*., 2016; Nindo *et al*., 2004) [1, 11, 20, 33] .

Utilizing low temperatures to dry foods can be advantageous in such a way that the thermo-liable bioactive compounds can be retained. But longer processing time due to slower drying can also degrade product quality. Increment in drying rate at such conditions can be achieved by lowering the Relative Humidity (RH) of the drying air by installing dehumidifiers in the drying system. Thus, the drying time is reduced and drying rate is improved significantly by enhancing the rate of mass transfer from product (Shewale & Hebbar, 2017) [47]. Low Temperature Low Humidity (LTLH) or Low Humidity Air (LHA) drying is an emerging technology employs this principle and renders high quality foods. Studies have reported the use of LTLH dryer for grains, herbs , spices and fruits (Nalawade *et al*., 2019; Ondier *et al*., 2010; Priyadarshi *et al*., 2020; Shewale *et al*., 2019a) [32, 36, 39, 48].

Although extensive studies have been carried out in both RWD and LTLH dryers, only a few literatures have reported the use of fruit slices as such for drying. Since a research gap exists in this area, the study aims at evaluating the changes in physical, chemical and nutritional properties of pineapple slices subjected to dehydration using RWD and LTLH dryers, with and without pre-treatment.

2. Materials and methods

2.1. Raw materials

Pineapples (*Ananas comosus*) were purchased from local market in Thanjavur, Tamil Nadu, India. The TSS of the fruits ranged from 12°-17° Brix which was measured by refractometer. The fruits were washed, peeled, de-cored and cut into 1.5 mm thick slices (70-90 mm diameter) using a fruit slicer.

2.2. Drying conditions

The pineapple slices were subjected to steam blanching at 100 ℃ for 1 min after which they were dabbed gently with blotting paper. The untreated control and blanched pineapple slices were subject to drying as follows:

2.2.1. Refractance Window drying

A laboratory scale RW dryer consisting of heating unit, thermocouple sensor, water bath (1 m × 0.5 m × 0.3 m) which is covered by food grade polyester film (ARYAPET®- A 250) of 100-micron thickness (Ganapathy Industries, Bangalore) was used for the experiment. Control and blanched pineapple slices were spread as a single layer (1.5 mm thickness) on the plastic film and dried till constant weight was obtained. The temperature of hot water was maintained at two different levels: 80 ℃ and 90 ℃, which was monitored by thermocouple sensors. The temperature of the plastic film and product was monitored at regular intervals using an infrared thermometer. The dried samples can be referred to as C80, B80, C90 and B90, where C and B represent control and blanched slices; 90 and 80 represent 90 ℃ and 80 ℃ temperatures, respectively.

2.2.2 LTLH dryer

A single layer of pineapple slices (control and blanched) were spread over the trays of LTLH dryer which consists of temperature and humidity control system. The experiment was carried out at constant temperature of 35 ℃ and at two different RH values: 10% and 20%. Drying was carried out until constant weight was obtained. The dried samples can be referred to as C10, B10, C20 and B20, where C and B correspond to control and blanched slices; 10 and 20 correspond to 10% and 20% relative humidity values respectively.

2.3 Drying characteristics

2.3.1. Moisture Content and water activity

The moisture content of the dried slices was determined by AOAC method (2000) [6]. The samples were dried in hot-air oven at 105 ± 1 ℃ until constant weight was obtained. The average value was considered. The moisture content can be calculated as:

$$\text{Moisture conent } (\%\text{ wb}) = \frac{(W_0 - W_1)}{W_0} \times 100 \qquad (1)$$

where, W_0 and W_1 are the weights of samples before and after drying, respectively.

The water activity of the samples was determined using water activity meter (AquaLab 4TE, Pullman, Washington (USA)). Triplicate values were taken and expressed as mean ± SD values.

2.3.2. Moisture Ratio

The moisture content obtained from the experiments were converted into a dimensionless Moisture Ratio (MR) by eq. (2)

$$MR = \frac{M_t - M_e}{M_0 - M_e} \qquad (2)$$

where, M_0, M_e and M_t are moisture contents are initial, equilibrium condition and at time ‘t’ (min), respectively, expressed as% wb.

2.3.3. Drying rate

The drying rate was calculated from the experimental moisture content values, using the eqn. (3)

$$\text{Drying rate (kg water/min)} = \frac{M_{t_1} - M_{t_2}}{t_2 - t_1} \qquad (3)$$

where, t_1 and t_2 are drying times (min) and M_{t_1} and M_{t_2} are moisture contents at time t_1 and t_2 respectively and expressed as% wb.

2.4. Physical properties

2.4.1. Color

The color of the fresh and dried samples were measured using colorimeter (Color flex EZ, Hunter Lab, Reston, VA). The color co-ordinates L^* (lightness/darkness), a^* (greenness/redness) and b^* (blueness/yellowness) were used to calculate the Total color difference (ΔE), Browning index

(BI) and Whiteness index (WI). WI is magnitude discoloration due to drying and BI is indicative of the purity of brown color in the dried sample (Hamid & Mohamed Nour, 2018) [17].

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (4)$$

where, L^*, a^* and b^* and L_0^*, a_0^* and b_0^* are the color values of dried and fresh samples respectively.

$$WI = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \quad (5)$$

$$BI = \frac{100\,(x - 0.31)}{0.17} \quad (6)$$

$$x = \frac{a + 1.75\,L^*}{5.645\,L^* + a - 3.012\,b^*} \quad (7)$$

2.4.2. Degree of Shrinkage

A screw gauge was used to measure the thickness and diameter of the pineapple slices before and after drying. Five slices were selected randomly and the average values were used to measure the volume. The degree of shrinkage was calculated using the eqn. (8)

$$S = \frac{V_t - V_0}{V_0} \quad (8)$$

where, V_t = Volume of slices after drying (m^3); V_0 = Volume of slices before drying (m^3)

2.4.3. Rehydration Ratio (RR)

Following the method proposed by (Lewicki & Wiczkowska, 2006) [24], known amount of dried pineapple slices were immersed in distilled water in 1:10 ratio in ambient temperature for 60 minutes. After withdrawing the samples, they were blotted gently to remove the surface water and weighed. The rehydration ratio can be calculated using the eqn. (9)

$$RR = \frac{w_R}{w_0} \quad (9)$$

where, w_R = Weight of the dried slices after rehydration; w_0 = Weight of the dried slices before rehydration. Experiments were carried out in triplicates and mean value was considered.

2.5. Nutrient composition

The crude protein present in pineapple slices was quantified by Kjeldahl method, using a conversion factor of 6.25 (AOAC, 2000) [6]. The crude fiber was determined following standard AOAC method (2000) [6] involving acid and alkali hydrolysis. The AOAC (2000) [6] method was used to determine the ash content. Triplicates were performed and the mean value was recorded. The eqn. (10) was used.

$$Ash\ (\%) = \frac{W_2}{W_1} \times 100 \quad (10)$$

where W_1 and W_2 are the weights of sample before and after ashing respectively.

2.6 Chemical composition

2.6.1. Ascorbic acid

The ascorbic acid (AA) content was quantified by 2,6–dichlorophenol-indophenol titration method (Li *et al*., 2014). The dye was titrated against standard 0.1 mg/ml of ascorbic acid (V_1). From the titre value, the dye factor was calculated ($0.5/V_1$). 0.5 g and 4 g of dried and fresh pineapple slices were taken respectively and extracted with 4% oxalic acid solution. The volume of the mixture was made up to 30 ml and centrifuged at 6,000 rpm for 15 minutes. 5 ml of the supernatant was diluted with 10 ml of 4% oxalic acid solution and titrated against the dye solution (V_2). Triplicates were performed. The ascorbic acid content was calculated as:

$$AA\ (mg/100\ g) = \frac{V_2 \times 0.5\ (mg) \times 100\ (ml)}{5\ (ml) \times V_1 \times \text{Sample weight}} \times 100 \quad (11)$$

2.6.2. Total phenol content

The Total Phenol Content (TPC) was found using Folin-Ciocalteau (FC) colorimetric method adapted from (Sew *et al*., 2014) [46]. 2 g of dried and fresh pineapple slices were ground thoroughly and taken in a test tube. 10 ml of 80% aqueous methanol was added for extraction and stirred overnight at room temperature. The mixture was then centrifuged at 6,000 rpm for 15 minutes. 30 µl of fruit extract, 150 µl of FC reagent and 3 ml of water was mixed and allowed to stand for 3 minutes. 0.45 ml of 20% sodium carbonate was then added. After incubating the mixture for 1 hour at room temperature, the absorbance values were taken at 765 nm wavelength using a spectrophotometer (Spectra Max iD3, Molecular Devices, California, USA). Standard curve was prepared using gallic acid with respect to which TPC was quantified and expressed in terms of mg GAE/100 g. Triplicates were performed.

2.6.3. Antioxidant activity

2.6.3.1 DPPH assay

2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH) assay was used to determine the free radical scavenging activity of pineapple slices. The method was adapted from (Vega-Gálvez *et al*., 2012) [53] with slight modifications. 1 ml of fruit extract was mixed with 1 ml of methanol and 2 ml of 0.15 mM DPPH. The mixture was vortexed for 10 s and incubated for 30 min in dark. The absorbance was measured at 517 nm using a micro-plate reader (Spectra Max iD3, Molecular Devices, California, USA). The Total Antioxidant Activity (AoA_{DPPH}) was expressed as percentage inhibition of DPPH radical, determined by eqn.

$$AoA_{DPPH}(\%) = \left[1 - \frac{Abs_{sample}}{Abs_{control}}\right] \times 100 \quad (12)$$

2.6.3.2 ABTS assay

The ABTS assay was performed in accordance to Aparecida De Assis *et al*. (2009) [7] with slight modifications. 5 ml of 7 mM ABTS solution was mixed with 88 µl of 140 mM potassium persulfate and was incubated for 16 h to produce ABTS radical cation. 1 ml of ABTS solution was diluted with 44 ml distilled water (1:44 ratio). 50 µl of fruit extract was mixed with 100 µl of ABTS solution and the absorbance value was read at 734 nm after 6 min incubation. The ABTS radical scavenging activity was expressed as percentage, using the eqn. 13.

$$AoA_{ABTS}(\%) = \left[1 - \frac{Abs_{sample}}{Abs_{control}}\right] \times 100 \quad (13)$$

where, Abs refers to absorbance.
The experiment was performed in triplicate.

2.7. Statistical analysis
The experimental results were processed in Minitab (version 17.1.0) and the significant differences between means were evaluated by One-way ANOVA and Tukey's test at 95% confidence level ($p<0.05$).

3. Results and Discussion
3.1. Drying characteristics
The initial moisture content and water activity of fresh pineapple was 86.5% (wb) and 0.965 respectively. The effect of RW and LTLH drying on the moisture content, moisture ratio and drying rate of the control and pre-treated pineapple slices is represented in figure 1 and 2, respectively. The time taken for drying C80, B80, C90 and B90 in RWD ranged from 480 – 540 min. The time taken by C10 and C20 for drying was 660 min whereas B10 and B20 dried in 420 min. The final moisture content (wb) of RW dried slices ranged from 5.33% - 7.17% at 80 °C and 4.67% – 6.64% at 90 °C, whereas in LTLH dried slices it ranged from 10% - 11% at 35 °C, 10% RH and from 11.33% - 11.83% at 35 °C, 20% RH. The corresponding water activities ranged from 0.366 to 0.393 in RWD and from 0.409 to 0.429 in LTLH. The pineapple slices that were pre-treated by steam blanching for 1 min had lower moisture content than their counterparts, because of increase in cell permeability during blanching, which enables faster moisture evaporation (Lewicki, 1998) [23].

In RWD, the temperature of hot water was maintained at 80 °C and 90 °C. But the temperature of the product was below 75 °C at any time of drying. Cichella Frabetti *et al*. (2018) [11] observed the temperature profiles during RW drying of guava pulp spread at different thickness on Mylar and Teflon film. The pulp temperature remained below 71 °C, even though the hot water was at 90 °C.

3.2. Physical properties
3.2.1 Color
The color retention of dried products is crucial for consumer acceptability as it can be considered as a criterion for quality retention. The color values of fresh and dried slices are recorded in Table 1. RW dried slices showed greater redness than LTLH because of oxidative reactions and Millard browning taking place at high temperatures. The degradation of b* value is a consequence of oxidation of carotenoids, which contributes to yellow color of pineapple (Saxena *et al*., 2012) [45]. This is in accordance to study performed by Chutintrasri & Noomhorm (2007) [10] where the effect of thermal properties on color characteristics of pineapple puree was studied. With increasing temperature, the lightness value reduced and redness value of the puree increased, indicative browning reactions. da Silva Simão *et al*. (2021) [13] studied the color parameters on restructured pineapple and discussed that conducive conditions for oxidation had resulted in reduction of yellowness. These changes during drying were accordingly reflected in WI and BI values. LTLH dried slices had better color retention when compared to RW dried slices. The obtained yellowness values were comparable to b* values obtained by Sarabo *et al*. (2019) [43] who studied the effects of pre-treatments on freeze-drying of pineapples. Similar results were obtained such that pre-treated slices had more b* values than that of control.

3.2.2. Degree of shrinkage
The degree of shrinkage of different treatments is presented in Table 2. The degree of shrinkage (DS) of the treatments ranged from 0.087- 0.136. All the treatments were significantly different from each other. The RW dried slices showed greater shrinkage than LTLH dried, which has an impact on rehydration properties and consumer acceptability. In LTLH, DS of C20 and B20 was slightly higher than C10 and B10, respectively. This may be because of the fact that shrinkage increases with increase in relative humidity (Agudelo-Laverde *et al*., 2014) [2]. DS of C90 and B90 are lower than C80 and B80, respectively. This is because of higher drying rates at 90 °C which quickly causes case-hardening than at 80 °C (Mahiuddin *et al*., 2018) [27]. Shewale *et al*. (2019b) [48] observed that shrinkage increased with increase in moisture content upto certain limit (33% wb). After this, due to slower drying rates, shrinkage decreased. It was also reported that less shrinkage in LTLH treated apples was observed due to crust formation on the product surface which leads to development of resistance to stresses due to drying.

3.2.3. Rehydration ratio
Rehydration property comes into play when reconstitution of dried foods is desired. The extent of tissue integrity due to drying affects the rehydration ability (Marques *et al*., 2009) [28]. The rehydration ratio of the dried slices is presented in Table 2. LTLH drying has produced slices with better reconstitution. This may be attributed to intact cell wall or increase in pore size of pineapple during LTLH drying. Shewale & Hebbar (2017) [47] stated that freeze-dried and LTLH dried apples exhibited better rehydration property when compared to conventional drying mainly because of increased porosity. Closure of pores as a result of shrinkage or caramelization could have rendered slightly lower RR in RWD (Jafari *et al*., 2016) [20]. It can be noted that the control had slightly higher RR than blanched samples. This is contrary to the general notion of increased rehydration properties in blanched products (Piotr P. Lewicki, 1998; Teferra *et al*., 2015) [23, 52]. Blanched slices have experienced more shrinkage which had negatively impacted the porous nature of the slices when compared to control. Similar results have been reported by Okpala & Ekechi (2014) [34]. The obtained RR of LTLH and RW dried slices in the current study was almost similar to values obtained by (Sarkar *et al*., 2020) [44] where applied Artificial Neural Network (ANN) was used to develop drying kinetics for pineapple in various dryers. The rehydration property was checked at different temperatures in which freeze-dried slices was the highest (4.50- 5.49).

3.3. Nutrient composition
All treatments showed an increase in protein, crude fiber and ash contents when compared to fresh slices. The values can be seen in Table 3. Highest protein content was found in C90 and B90. C90, B90 and C80 contained highest fiber content. Ash content was greater in B90 and B20. During drying, the inherent nutrients present in the fruit tends to become concentrated (Chang *et al*., 2016) [9]. Wijewardana *et al*. (2016) [57] produced fruit powders from bael fruit and palmyra by using different drying techniques. The proximate analysis of the powders showed a significant increase in nutrients than control, showcasing the beneficial effect of dehydration. Ain & Amin (2014) [3] performed a study which involved freeze-drying of fresh and pre-treated pineapples. The study reported protein percentage values similar to that of C90 and B90

protein values, ash content lower than B20 and similar fiber content with respect to the current study. The ash content of blanched samples was greater than their control counterparts. On the contrary, the crude fiber content of the steam-blanched samples was lesser than control. This was similar to the results obtained by Teferra *et al*. (2015) [52] where the effect of pre-treatments in drying of carrot was studied. The crude fiber content of the carrot was a function of blanching temperature. Blanching at higher temperatures showed a decrease in crude fiber content.

3.4. Chemical composition

The ascorbic acid content, TPC and antioxidant activities of fresh and dried slices are presented in Table 4.

3.4.1. Ascorbic acid

Ascorbic acid (AA) is thermolabile and also sensitive to heavy metals, light and relative humidity. The extent of ascorbic acid retention can be a reflection of inherent quality retention in dried foods. Performing operations like cutting, peeling and slicing can also deplete ascorbic acid as it involves cell disruption due to which enzymatic degradation takes place (Marques *et al*., 2014) [29]. The ascorbic acid (AA) present in fresh pineapple is 33.824 ± 1.47 mg/100g. This is in accordance to the value obtained by Vinci *et al*. (1995) [55]. The RW dried slices had better retention (57% - 89%) than LTLH (24% - 67%). The role played by relative humidity in degrading the ascorbic acid content is evident in LTLH drying since the temperature is maintained constant (35 °C). So, the reduction in ascorbic acid is related to the changes in equilibrium moisture content brought about by relative humidity. The effects of temperature, velocity and relative humidity was studied by Kaya *et al*. (2010) [22] using kiwifruit. It was concluded that the Vitamin C degradation was a function of relative humidity at constant temperature (35 °C) and vice-versa. The greatest loss was recorded at the lowest RH values. The AA degradation in RW drying is mainly caused by employing high temperatures and enzymatic degradation. Jalgaonkar *et al*. (2020) [21] witnessed an increment in AA retention with an increase in water temperature until 91 °C during the preparation of sapota bar using RW dryer. Despite the water temperature in RW dryer being 80 °C and 90 °C, the product temperature always remained below 75 °C, thus having lesser degradation than LTLH dried slices. da Silva Simão *et al*. (2021) [13] has reported similar trend wherein there was no significant difference in AA content of fresh and restructured pineapple in Cast-tape drying (CTD) and conductive multi-flash drying (KMFD). Rajoriya *et al*. (2019) [41] reported better AA retention with increase in temperature mainly due to shorter drying time and lower product temperature than hot water. Freeze-drying of pineapple had caused an increase in AA content (17.8 ± 0.6 mg/100g) as reported by Olivas-Aguirre *et al*. (2017) [35]. But Marques *et al*. (2006) [30] reported a decrease in AA from 41.05 to 30 mg/100g of pineapple. Similar values were obtained in the current study and thus shows the effectiveness of RWD in quality preservation.

3.4.2. Total phenol content

The total phenol content (TPC) of all treatments were significantly greater than the fresh pineapple (110.59 ± 5.24 mg GAE/100 g).The TPC value of fresh pineapple as reported by Zzaman *et al*. (2021) [58] was 183.13 ± 1.69 mg/100 g. The phenol profile of all the treatments improved significantly compared to fresh pineapple. Özcan *et al*. (2020) [38] reported that microwave drying showed an increase in TPC fresh kiwi and pepino fruits than control. The author claimed that the concentration of phenols during moisture transfer exhibited this increment. Hernández-Santos *et al*. (2016) [18] conducted a comparative study on the effects of thickness and temperature on the quality characteristics of carrot in RW dryer and conventional dryer wherein the TPC of RW dried carrots seemed to be almost the same as control. The author suggested that owing to very high drying rate, the moisture evaporated from the product creates high vapor pressure near the product which makes it difficult for the phenols in the cells to get oxidized. The extractability of phenols is enhanced after drying as a result of cell disruption (Szychowski *et al*., 2018) [51]. C90 and B90 had slightly better phenol profile than all treatments. Blanching did not significantly impact TPC of dried slices. da Silva *et al*. (2013) [14] witnessed an increase in phenolic content after fixed-bed drying of pineapple residues and stated that eve n though disruption of cell structure can emit degradative enzymes, they are rendered inactive at higher temperatures. This could be the reason for RW drying to have marginally better profile than LTLH drying. Although low temperature is used in LTLH, enzymatic degradation could have affected the phenolic profile (Shewale & Hebbar, 2017) [47]. TPC of RW and LTLH dried slices were similar to the values reported by Olivas-Aguirre *et al*. (2017) [35]. Freeze drying had reduced the TPC slightly but not significantly in the study performed by Izli *et al*. (2018) [19]. But both the dryers used in this study increased the phenolic profile.

3.4.3. Antioxidant activity

The DPPH and ABTS assays are commonly used for determining the antioxidant activities of fruits (Olivas-Aguirre *et al*., 2017) [35]. The DPPH radical scavenging activity of the fresh pineapple was 96.8 (%). This value was comparable to DPPH value obtained by Alothman *et al*. (2009) [4]. DPPH and ABTS values of LTLH dried slices were similar to fresh pineapple. But RW dried slices had lower DPPH inhibition (%) but similar ABTS value with respect to fresh pineapple. (Bushra Sultana, 2012) [8] performed antioxidant assay after subjecting certain fruits to ambient and oven drying. The author stated that the reason for decrease in antioxidant activity was because of using high temperatures. As RW drying employs higher temperatures than LTLH, there might be significant decrease in DPPH values. Studies performed by da Silva Simão *et al*. (2021) [13] showed a significant decrease in antioxidant activity of restructured pineapple snacks when comparing fresh pineapple with Cast-Tape dried and KMFD samples. A decrease in 47% of antioxidant activity was evaluated by DPPH assay. But around 96% of antioxidant activity retention was exhibited by RW dried slices in the current study. Izli *et al*. (2018) [19] explained the negative impact of longer drying times on antioxidant activity even at lower temperatures. But the LTLH dried slices did not exhibit any significant decrease despite using lower temperature. There was no significant impact exerted by pre-treatment with respect to control. Also, there was no significant difference between temperature levels or different RH values in RW and LTLH dryer, respectively. The obtained results were comparable to the values reported by Izli *et al*. (2018) [19] where freeze-dried pineapples were examined.

4. Conclusion

The study evaluated the impact of two novel drying technologies, RW and LTLH drying, on various quality characteristics of pineapple slices namely physical, chemical and nutritional properties. Pre-treatment prior to drying, like blanching, did not have any significant impact on majority of the quality parameters but played a major role in reducing the drying time. Both the drying techniques have rendered products that possess qualities comparable to that of freeze-drying, available in the literature. LTLH drying resulted in slices having better physical properties like color and rehydration properties. But the retention of nutrients and other chemical characteristics play a major role in consumer purchase behavior and health. RW drying facilitates better nutrient concentration and most importantly, retains more ascorbic acid and total polyphenols than LTLH drying. This particular aspect can enhance the scope for harnessing RW drying of purees, juices, probiotics, gels, pastes, etc. Further investigation on preserving the physical characteristics can help in increasing consumer appeal. LTLH dryer has been mainly used for grains, spices and herbs but its potential use in other food categories can be also be explored.

Table 1: Color values of RW and LTLH dried pineapple slices

S. No.	Treatment	L*	a*	b*	ΔE	WI	BI
1	Fresh	72.0567 ± 0.0379^{b}	0.7600 ± 0.0529^{g}	38.860 ± 0.260^{a}	-	-	-
				RW dried			
1	C80	68.8400 ± 0.0889^{d}	4.8067 ± 0.0737^{d}	33.690 ± 0.435^{d}	7.319 ± 0.231^{d}	53.858 ± 0.377^{b}	70.079 ±1.321^{f}
2	B80	56.817 ± 0.408^{f}	9.3167 ± 0.1250^{c}	35.9667 ± 0.1358^{bc}	17.719 ± 0.425^{b}	43.033 ± 0.276^{e}	106.168 ± 0.960^{c}
3	C90	52.8367 ± 0.1012^{g}	12.2300 ± 0.0624^{a}	33.7533 ± 0.0929^{d}	22.9605 ± 0.1017^{a}	40.7273 ±0.0846^{f}	112.554 ± 0.463^{b}
4	B90	52.020 ± 0.370^{h}	10.860 ± 0.299^{b}	36.163 ± 0.255^{b}	22.603 ± 0.491^{a}	38.943 ± 0.206^{g}	124.100 ± 0.727^{a}
				LTLH dried			
1	C10	72.8200 ± 0.1044^{a}	0.9667 ± 0.0252^{g}	29.4733 ± 0.0896^{e}	9.4201 ± 0.0813^{c}	59.8954 ± 0.0055^{a}	51.2978 ± 0.102^{g}
2	B10	70.4833 ± 0.1069^{c}	0.25333 ± 0.01528^{h}	36.587 ± 0.264^{b}	2.817 ± 0.218^{f}	52.990 ± 0.224^{c}	70.157 ± 0.741^{ef}
3	C20	70.070 ± 0.471^{c}	4.3567 ± 0.0321^{e}	35.477 ± 0.206^{c}	5.3401 ± 0.0672^{e}	53.380 ± 0.461^{bc}	72.543 ± 1.224^{e}
4	B20	63.530 ± 0.203^{e}	3.8600 ± 0.0954^{f}	39.3233 ± 0.1193^{a}	9.088 ± 0.224^{c}	46.229 ± 0.175^{d}	94.931 ± 0.733^{d}

Values are expressed as mean ± standard deviation. Values with different superscripts in the same column are significantly different ($p \leq 0.05$). C80 and B80 represent control and blanched slices dried at 80 °C; C90 and B90 represent control and blanched slices dried at 90 °C; C10 and B10 represent control and blanched slices dried at 35 °C, 10% RH; C20 and B20 represent control and blanched slices dried at 35 °C, 10% RH

Table 2: Rehydration ratio, degree of shrinkage of RW and LTLH dried pineapple slices

S.No	Treatment	Rehydration Ratio	Degree of shrinkage
		RW dried	
1	C80	4.250 ± 0.191^{b}	0.117788 ± 0.000238^{c}
2	B80	4.123 ± 0.410^{b}	0.135563 ± 0.000111^{a}
3	C90	4.448 ± 0.267^{ab}	0.105468 ± 0.000525^{d}
4	B90	4.209 ± 0.193^{b}	0.120571 ± 0.000806^{b}
		LTLH dried	
1	C10	4.9033 ± 0.0306^{ab}	0.086791 ± 0.000241^{h}
2	B10	4.6500 ± 0.0400^{a}	0.092601 ± 0.000009^{f}
3	C20	4.338 ± 0.245^{ab}	0.090146 ± 0.000018^{g}
4	B20	4.2414 ± 0.1333^{b}	0.094053 ± 0.000019^{e}

Values are expressed as mean ± standard deviation. Values with different superscripts in the same column are significantly different ($p \leq 0.05$). C80 and B80 represent control and blanched slices dried at 80 °C; C90 and B90 represent control and blanched slices dried at 90 °C; C10 and B10 represent control and blanched slices dried at 35 °C, 10% RH; C20 and B20 represent control and blanched slices dried at 35 °C, 10% RH

Table 3: Effect of RW and LTLH drying on protein, fiber and ash contents of pineapple slices

S. No	Treatment	Protein (%)	Fiber (%)	Ash (%)
1	Fresh	0.9333 ± 0.1010^{e}	1.167 ± 0.382^{e}	0.99029 ± 0.01682^{g}
			RW dried	
1	C80	4.3167 ± 0.1010^{d}	10.5500 ± 0.0866^{ab}	2.0000 ± 0.1000^{f}
2	B80	5.1333 ± 0.1010^{b}	9.867 ± 0.231^{bc}	4.517 ± 0.351^{b}
3	C90	7.583 ± 0.202^{a}	11.167 ± 0.289^{a}	2.9500 ± 0.1323^{cd}
4	B90	7.4667 ± 0.1010^{a}	10.333 ± 0.289^{ab}	5.5333 ± 0.0577^{a}
			LTLH dried	
1	C10	4.550 ± 0.175^{cd}	10.333 ± 0.289^{ab}	2.168 ± 0.303^{ef}
2	B10	4.608 ± 0.440^{bcd}	9.000 ± 0.500^{cd}	2.5267 ± 0.1665^{de}
3	C20	5.017 ± 0.202^{bc}	9.600 ± 0.278^{bcd}	3.4333 ± 0.1155^{c}
4	B20	5.017 ± 0.202^{bc}	8.750 ± 0.661^{d}	5.6000 ± 0.1000^{a}

Values are expressed as mean ± standard deviation. Values with different superscripts in the same column are significantly different ($p \leq 0.05$). C80 and B80 represent control and blanched slices dried at 80 °C; C90 and B90 represent control and blanched slices dried at 90 °C; C10 and B10 represent control and blanched slices dried at 35 °C, 10% RH; C20 and B20 represent control and blanched slices dried at 35 °C, 10% RH

Table 4: Effect of RW and LTLH drying on ascorbic acid, total phenols and antioxidant activity of pineapple slices

S. No	Treatment	Ascorbic acid (mg/ 100g)	TPC (mg GAE/ 100 g)	Antioxidant Activity (%)	
				ABTS	DPPH
1	Fresh	33.824 ± 1.471^{a}	110.59 ± 5.24^{e}	94.81 ± 4.99^{a}	96.750 ± 0.435^{a}
		Refractance Window dried			
1	C80	30.20 ± 1.80^{a}	935.6 ± 34.4^{ab}	77.04 ± 3.91^{a}	93.790 ± 0.967^{b}
2	B80	29.569 ± 0.272^{a}	855.4 ± 109.7^{abc}	85.21 ± 2.40^{a}	93.533 ± 0.537^{b}
3	C90	29.647 ±0.408^{a}	1045 ± 206^{a}	87.012 ± 0.567^{a}	92.719 ± 0.465^{b}
4	B90	19.41 ± 2.56^{b}	1043.0 ± 73.5^{a}	84.92 ± 6.00^{a}	93.445 ± 0.323^{b}
			LTLH dried		
1	C10	10.20 ± 1.80^{c}	646.1 ± 64.2^{d}	72.62 ± 11.25^{a}	96.396 ± 0.435^{a}
2	B10	7.84 ± 3.40^{c}	729.9 ± 29.9^{bcd}	70.7 ± 22.1^{a}	96.171 ± 0.390^{a}
3	C20	23.5294 ± 0.0000^{b}	495.9 ± 61.8^{cd}	94.914 ± 0.686^{a}	96.6480 ± 0.0968^{a}
4	B20	11.7647 ± 0.0000^{c}	654.7 ± 50.8^{cd}	89.01 ± 4.80^{a}	96.5549 ± 0.1707^{a}

Values are expressed as mean ± standard deviation. Values with different superscripts in the same column are significantly different ($p \leq 0.05$). C80 and B80 represent control and blanched slices dried at 80 °C; C90 and B90 represent control and blanched slices dried at 90 °C; C10 and B10 represent control and blanched slices dried at 35 °C, 10% RH; C20 and B20 represent control and blanched slices dried at 35 °C, 10% RH

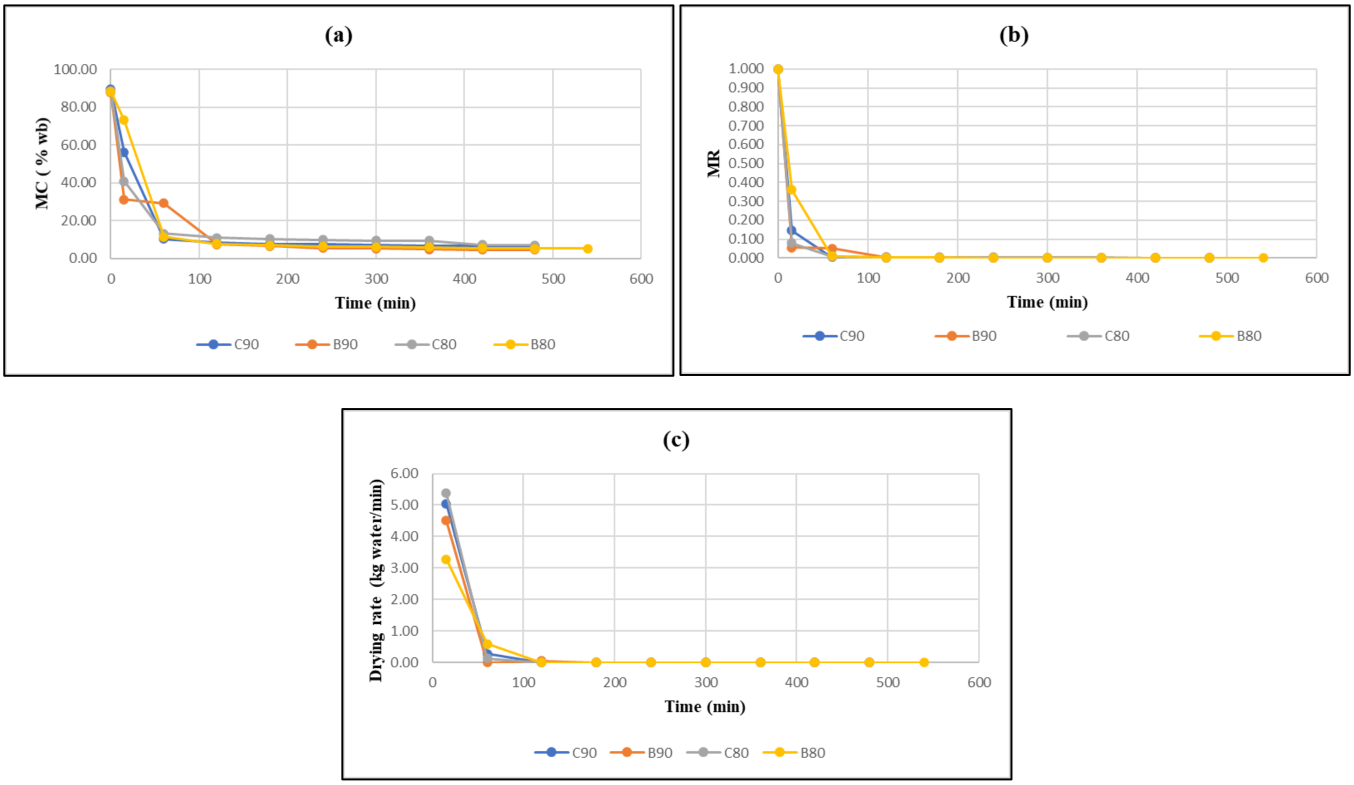
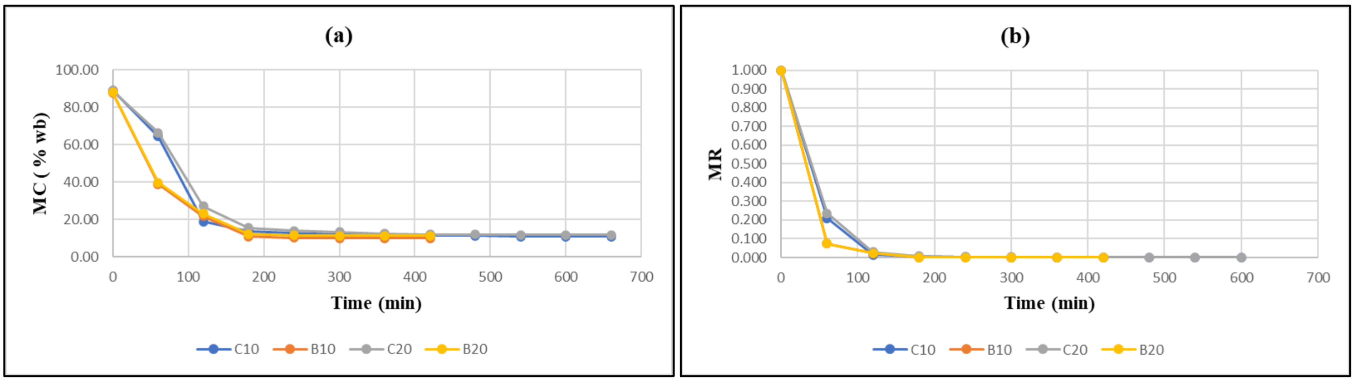


Fig 1: Effect of different treatments on (a) moisture content (b) moisture ratio and (c) drying rate in RWD. C80 and B80 represent control and blanched slices dried at 80 °C; C90 and B90 represent control and blanched slices dried at 90 °C



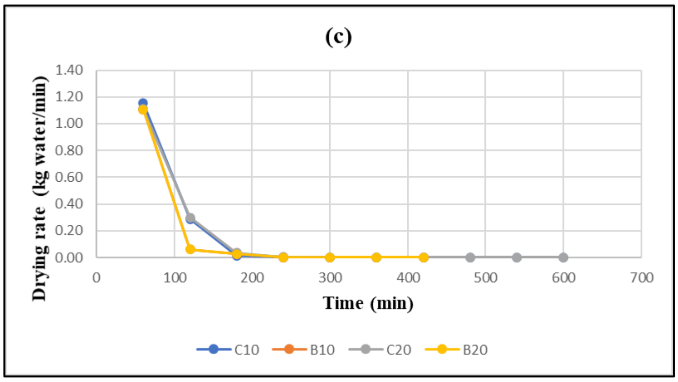


Fig 2: Effect of different treatments on (a) moisture content (b) moisture ratio and (c) drying rate in LTLH. C10 and B10 represent control and blanched slices dried at 35 °C, 10% RH; C20 and B20 represent control and blanched slices dried at 35 °C, 10% RH

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