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OPTIMIZATION OF HOT AIR DRYING PARAMETERS AND PHYSICO-CHEMICAL CHARACTERISTICS OF APPLE BER

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ABSTRACT
Many nutritious fruits are underutilized because of various reasons and one among them is limited shelf life. This problem can be eradicated by dehydrating the fruit in an efficient way without losing its nutritive values. The study emphasis on the drying characteristics of Apple ber fruit and to reap maximum benefit out of it. Drying parameters were suitably chosen which gives better results. Hot air oven was used for dehydrating the fruit and the results are analysed to fix the desired parameters. The temperature was varied to find the drying rate, moisture ratio and moisture diffusivity at a time interval of five minutes. Temperature was set at 45oC, 50oC, 55oC, 60oC and 65oC. Results depicted that the drying rate increases with temperature at shorter time however the quality of the yield is optimum at 55oC. Out of the seven drying models, midilli model was optimally fit with the observed rate of drying.
Keywords: apple ber; drying models; hot air oven; MOR; DRR; EMD; SEC; HAR;CAI; Color coordinates; functional properties

Abbreviations:

HAD: Hot Air Drying
MOR: Moisture Ratio
DRR: Drying Rate
EMD: Effective Moisture Diffusivity
E_a: Activation Energy
SEC: Specific Energy Consumption
a_w : Water Activity
WAHC: Water Holding Capacity
OIHC: Oil Holding Capacity
SWC: Swelling Capacity
WSI: Water Soluble Index

SHR: Shrinkage Ratio
RR: Rehydration Ration
BD: Bulk Density
TD: Tapped Density
HAR: Hausner Ratio
CAI: Carr Index
CC: Colour Coordinates
HS: Hygroscopisity
DC: Degree of Caking
TPC: Total Phenolic Content
TFC: Total Flavonoid Content
DPPH: 2,2-diphenylpicrylhydrazyl
ABTS: ,2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid

1. INTRODUCTION

To prolong the preservation of fruits, they undergo a drying process that has been practiced since ancient times. Heat sources such as sunlight, hot air, and fire are employed to remove moisture from the fruits, a method also referred to as dehydration. While the terms drying and dehydration are often used interchangeably, drying typically involves reducing the water content to an equilibrium moisture level, while dehydration entails removing water until the fruit reaches an almost entirely dry state.

Dried fruit loses its weight but not the taste which can be preserved for a longer time. Drying doesn't affect much the nutrient values. According to My Plate and the USDA's *Dietary Guidelines for Americans*, ½ cup of dried fruit is equivalent to 1 cup of fresh fruit. These dried fruits can be powdered and can be incorporated in various food products to derive the health benefits. The quality of powder produced determines the quality of the product produced (Dadali *et al.* 2007).

Many fruits cannot be cultivated in all the parts of the country. Also they are not available throughout the year. Hence products cannot be consistently produced with these fruits throughout the year without effectively preserving it in the right form. Fruits dried and powdered can be used for a longer period and it can be readily mixed with other ingredients to prepare a healthy food product. Powdered fruits can be easily packed and consumes very less space.

Loss of nutrients, variation in colour, poor texture and loss of aroma may occur during the drying process. The drying process must be carefully designed to minimize all these adverse effects of drying. In this study the drying process is carried out using Hot air oven. Hot air oven was used for dehydrating the fruit and the results are analyzed to fix the desired parameters. The temperature and time were varied to find the drying rate, moisture ratio and moisture diffusivity. The thermostat is employed to regulate the temperature of the hot air that circulates over the fruit being dried. Drying can be conducted at different temperatures to achieve the desired characteristics in the resulting dried fruits.

The behavior of characteristics of fruits during the drying process can be predicted by Mathematical modeling. Mathematical modeling is formulated using mathematical equations (**Wang et al., 2004**).Variables like temperature distribution, moisture absorption rate, velocity etc. are more complicated to analyze without the help of mathematical modeling. It also helps to analyze and compare the performance of driers and drying processes (**Abera et al., 2016; Defraeye, 2014**). There are two main classifications of mathematical models for fruit drying: semi-theoretical equations and theoretical equations. Semi-theoretical equations are suitable for thin-layer drying, while theoretical equations are based on the fundamental physics of drying.

Semi-theoretical models have historically been effective for modeling fruit drying kinetics. However, as numerical computation advances, theoretical models are increasingly favored due to their improved relevance and understanding of fruit drying processes. (**Erbay and Icier (2010), Ertekin and Firat (2015) and Putranto et al. (2011)**).

The aim of this study is to explore the dried apple ber fruit pulp through hot air drying (HAD) at varying temperatures. Additionally, it seeks to analyze the drying characteristics of apple ber fruit pulp using HAD, validate and compare different mathematical models of thin-layer drying techniques to interpret observed data, and assess the physicochemical and functional properties of both fresh and dried pulp.

Materials and Methods

2.1 Drying Characteristics

2.1.1 Moisture Ratio (MOR)

Moisture ratio indicates the mass loss of the sample during the drying process. It is the ratio of final MC to the initial MC of the sample at given time and temperature and calculated using the below equation 1 **(**Chakraverty and Singh, 2014).

$$\mathrm{MOR} = \frac{\mathrm{M_{ti}} - \mathrm{M_{eq}}}{\mathrm{M_{in}} - \mathrm{M_{eq}}} \qquad (1)$$

2.1.2 Drying Rate (DRR)

DRR determines the time required for the drying process. It shows the rate of evaporation from the inner portion to the surface of the sample and then evaporated to the surroundings (Chakraverty and Singh, 2014). DRR is calculated using the equation 2.

$$\mathrm{DRR} = \frac{\mathrm{M_{ti+dti}} - \mathrm{M_{ti}}}{\mathrm{d_{ti}}} \qquad (2)$$

Where, M_{ti} and d_{ti} indicates the Moisture evaporated at particular time and change in time taken for drying

2.1.2 Effective Moisture Diffusivity (EMD)

EMD was calculated using second law of Fick and also it explains the mechanism of water transfer to the surface (Garba, 2015; Kumar, 2012; Aral and Bese, 2016). Based on the equation 3, EMD was calculated

$$\ln(MOR) = ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}\, t_i}{4L^2}\right) \qquad (3)$$

Where, D_{eff} is EMD (m^2/s), L is sample thickness and $t_i$is drying time (s).

2.1.3 Activation Energy (E_a)

E_a determined the energy required to remove the moisture present in the sample with the specific moisture content and available composition under HAD method (Doymaz 2010). E_a was calculated using the equation 4

$$\ln(D_{eff}) = ln(D_0) - \left(\frac{E_a}{RT}\right) \qquad (4)$$

2.1.4 Specific Energy Consumption (SEC)

SEC is energy required for evaporating moisture from the sample (Pillai 2013) which helps in understanding the energy consumption and calculates the actual cost associated with the process of drying. SEC was calculated using the equation 5.

$$SEC = (\mathrm{C_a} + \mathrm{C_v h_a}) \qquad (5)$$

2.1.5 Mathematical Modelling

In Table 1, the different thin layer models utilized for mathematically modeling the experimental data from both drying methods are presented. The analysis of these models was conducted using MATLAB software, specifically its curve fitting tool, to determine the best fit.

Table 1 Thin layer drying models

Model Name	Model Equation	Researcher
Page	$MOR = \exp(-kt^n)$	Sarimeseli (2011)
Newton	$MOR = \exp(-kt)$	O'Callaghan et al. (1971)
Handerson and Pabis	$MOR = a\exp(-kt)$	Roberts et al.(2008)
Midilli et.al	$MOR = a\exp(-kt^n) + bt$	Midilli et al. (2002)
Logarithmic	$MOR = a\exp(-kt) + c$	Akpinar (2008)
Modified Page	$MOR = \exp((-kt)^n)$	Yaldiz et.al(2005)
Wang and Singh	$MOR = 1 + at + bt^2$	Arslan and Ozcan (2010)

2.2 Physicochemical Properties

2.2.1 Water Activity (a_w)

Water activity for the fresh and dried sample was measured using digital water activity meter (Aqualab 4TE, USA). (Tze 2012). Triplicate readings were taken for each sample and average value was computed.

2.2.2 Water Holding Capacity (WAHC) and Oil Holding Capacity (OIHC)

The WAHC and OIHC were determined by adding 100 ml of distilled water for WAHC and oil for OIHC to the known weight of the sample. After a 30-minute incubation period, the mixture was centrifuged at 6500 rpm for an additional 15 minutes. The residue was collected and weighed (Aziah and Komathi 2009) to calculate the value of WAHC and OIHC using the equations 6 & 7.

$$WAHC\ (\%) = \frac{W}{} \quad (6)$$

$$OIHC\ (\%) = \frac{W}{} \quad (7)$$

2.2.3 Swelling Capacity (SWC) and Water Soluble Index (WSI)

SWC and WSI of the sample was determined by the Hu *et al.* (2009) and Romero-Bastida *et al.* (2005) method. The initial weight (M_0) was measured and noted. The known weight of the sample was taken in a sealed beaker along with 50 ml of distilled water and kept for 24 hours without evaporation. Then the drying process was carried out until the weight reaches a constant value. The final weight was measured and the average of triplicate value was used in the equation 8 and 9 to calculate the SWC and WSI.

$$\text{SWC (\%)} = \frac{M_1 - M_0}{M_0} \text{ X } 100 \quad (8)$$

$$\text{WSI (\%)} = \frac{M_0 - M_1}{M_1} \times 100 \quad (9)$$

2.2.4 Shrinkage Ratio (SHR)

The SHR was determined using the water displacement method, where dried samples weighing W1 were submerged in water held in a 150 ml flask. The weight W2 was then measured, and equation 10 was employed to calculate the SHR value. (Koc*et al.* 2008).

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

2.2.5 Rehydration Ration (RR)

The known weight of the sample was mixed with 150 ml of distilled water and boiled for about 15 minutes and dehydrated to measure the final weight (Maskan 2001). The differences in the weight helps to compute the RR value using the equation 11.

$$RR(\%) = \frac{W_{rs}}{W_{ds}} \text{ x } 100 \quad (11)$$

2.3 Flowability properties

2.3.1 Bulk Density (BD) and Tapped Density (TD)

The apple ber fruit powder was weighed before it was filled in the empty measuring cylinder (Chegini and Ghobadian 2005) for calculating BD and it was mechanically tapped to calculate TD. The BD and TD were calculated using the equations 12 and 13.

$$\text{BD}(\rho_B) = \frac{\text{Mass of fruit pulp powder,g}}{\text{Volume of fruit pulp powder,cm}^3} \quad (12)$$

$$\text{TD }(\rho_T) = \frac{\text{Mass of fruit pulp powder,g}}{\text{Final tapped volume,cm}^3} \quad (13)$$

2.3.2 Hausner Ratio (HAR) and Carr Index (CAI)

BD and TD values were used to calculate the HAR and CAI. These two parameters helps to determine the flow ability of the dried pulp powder. CAI gives the compressibility of the powder (Carr 1965) and the granular material represented by the HAR (Dehghannya, *et al.* 2019). These two parameters can be estimated by the equations 14 and 15.

$$\text{HAR} = \frac{\rho_T}{\rho_B} \quad (14)$$

((15)

2.3.3 Colour Coordinates (CC)

The color characteristics of both fresh and dried samples were assessed using the Hunter LAB color scale, with parameters reported as L, L*, a, a*, b, and b*. The presence of a reddish hue is indicated by positive values of a*, while negative values suggest a greenish tint. Similarly, a positive value of b* signifies a yellowish color, while a negative value of L* indicates a bluish hue. The average of six values were calculated to find the values of ΔE, C^*, H^*, WI, BI and YI. The equations 16,17,18,19,20,21 and 22 were used to calculate the parameters.

$$\Delta E = ((a^* - a_0)^2 + (b^* - b_0)^2 + (L^* - L_0)^2)^{0.5} \quad (16)$$

$$C^* = \sqrt{{a^*}^2 + {b^*}^2} \quad (17)$$

$$H^* = \tan^{-1}\left({b^*}/{a^*}\right) \quad (18)$$

$$WI = \sqrt{(100 - L^{*2}) + a^{*2} + b^{*2}} \quad (19)$$

$$BI = 100 \times \frac{X - 0.31}{0.17} \quad (20)$$

Where X can be calculated using the equation 21

$$X = \left(\frac{a^* + 1.75L^*}{5.645L + a^* - 3.012\,b^*}\right) \quad (21)$$

$$YI = \frac{142.86 \times b^*}{L^*} \quad (22)$$

2.3.4 Hygroscopisity (HS)

Known amount of dried pulp powder was spread on a 90 mm diameter Petri plate and placed on a stand in a glass desiccators. Saturated solution of sodium chloride ($NaCl_2$) was used to obtain a relative humidity of 79.5% inside the desiccators. After sealing the desiccators' chamber, powders were held at above specified humidity for up to a week and sample weight was measured until reached a constant weight. The Hygroscopicity was measured by using the below formula (Jaya and Das 2004).

$$HS\,(\%) = \frac{\frac{X}{Y} + M_{in}}{1 + \frac{X}{Y}} \times 100 \quad (23)$$

Where X and Y is the sample weight at initial condition and Y is the sample weight after a period of one week; M_{in} is the IMC of sample.

2.3.5 Degree of Caking (DC)

Known amount of dried pulp powder was spread on a 90 mm diameter Petri plate and placed on a stand in glass desiccators. Saturated solution of sodium chloride ($NaCl_2$) was used to obtain a relative humidity of 79.5% inside the desiccator. After sealing the desiccator chamber, powders were held at above specified humidity for up to a week and sample weight was measured until reached a constant weight. Later, the powder was dried at 105 °C in the oven. After the drying process the powder was sieved with the modified mesh of 1,200 μm (Aguilera *et al.* 1995). Degree of caking can be calculated using the following formula.

$$DC\ (\%) = \frac{b}{a} \times 100 \quad (24)$$

Where a and b is the weight of powder passed through the sieve and retained in the sieve

2.4 Functional Properties

2.4.1 Total Phenolic Content (TPC)

The TPC value was determined using the Folin-Ciocalteu method. A 1 ml extract was placed into a beaker and combined with 10 ml of distilled water and 1.5 ml of Folin-Ciocalteu reagent. After thorough stirring for approximately 1 minute, 6 ml of 10% (w/v) sodium carbonate solution was added. The mixture was then brought to a total volume of 25 ml with distilled water. Absorbance was measured at 760 nm using a spectrophotometer (Elico SL 244). TPC values were calculated in terms of gallic acid equivalent (mg GAE/g) using a gallic acid calibration curve (Lin and Tang 2007).

2.4.2 Total Flavonoid Content (TFC)

To calculate the value of TFC, 4 ml of distilled water and 0.3 ml of 5 % (w/v) $NaNo_3$ solution was added to the known weight of the sample and stored for 5 minutes. Then 10 % (w/v) aluminium chloride solution was added and stored for 6 minutes. Later, 2 ml of sodium hydroxide was added to the mixture to determine the absorbance at 510 nm. The quercetin standard curve was used to determine the value of TFC. It is denoted as quercetin equivalents (mg QE/g) (Lin and Tang 2007).

2.4.3 DPPH (2,2-diphenylpicrylhydrazyl)

1 ml of fresh and dried pulp extracts were taken in various concentrations (0.5 to 2.5 mg/ml with an interval of 0.5 mg/ml) and mixed with 4 ml of DPPH solution. The mixture is stirred well and in incubator (room temperature) for 30 minutes. The absorbance was recorded at 517 nm for different concentration and standard plot was derived using AA (Wootton*et al.* 2011). The value of DPPH was determined by the equation 25.

$$\text{DPPH Scavenging activity}\ (\%) = \left[1 - \left(\frac{ABS_{Sample}}{ABS_{Control}}\right)\right] \times 100 \quad (25)$$

2.4.4 ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid))

The ABTS radical decolorization assay was utilized to evaluate the radical scavenging capacity of the fruit pulp sample, following the method outlined by Oszmiański et al. (2015). Initially, the ABTS•+ radical cation was generated by combining a 7.0 mM ABTS stock solution with 2.45 mM potassium persulfate, followed by a 16-hour incubation at room temperature in darkness. Afterward, ethanol was mixed with the ABTS•+ solution and diluted to achieve an absorbance value of 0.7 at 734 nm. Sample aliquots were then adjusted to a 1 ml volume using ethanol. Subsequently, the diluted ABTS•+ solution (1.0 ml) was thoroughly mixed with the sample aliquots, and the absorbance of the resulting oxidation solution was measured at 734 nm.

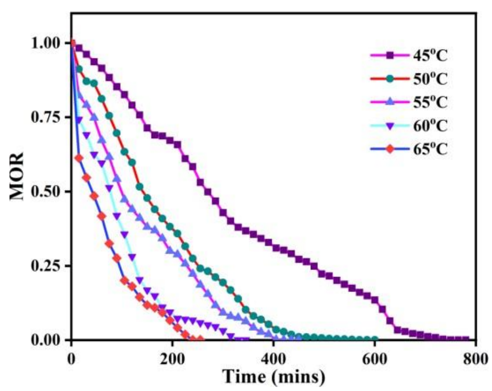
2. RESULTS AND DISCUSSION

3.1 Drying Characteristics

The results obtained were summarized and the possibilities of utilizing this fruit are discussed in this section. The research involved adjusting the hot air temperature within the range of 45°C to 65°C, with increments of 5°C, while examining all parameters.

3.1.1 Moisture Ratio (MOR) & Drying Rate (DRR)

MOR & DRR increases with the increase in temperature. At elevated temperatures (65°C), heat transfers more rapidly from the outer to the inner layers of the pulp, resulting in the moisture being drawn from the inner surface to the outer surface in a shorter duration. Hence the DRR increases with drying temperature. Also, the rate of mass transfer was also found to be higher due to the high internal vapour pressure when compared to the samples dried at lower temperature (45ºC) (Motevali *et al.* 2014). The results obtained are depicted in the figure 1 and 2.



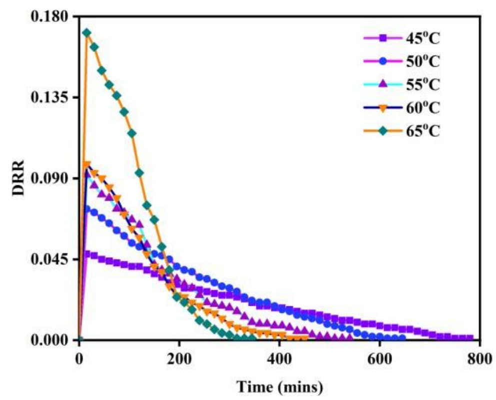


Figure-1 and 2 Effect of different temperature on MOR& DRR

3.1.2 Effective Moisture Diffusivity (EMD)

EMD provides a thorough explanation of the diffusion phenomena associated with heat and mass transfer processes during the drying process. The influence of air temperature (45 to 65ºC) on EMD is given in the Table 2.

Table 2 Effect of different temperature on EMD

Temperature (ºC)	**EMD (m^2/s)**
45	5.96×10^{-10}
50	6.54×10^{-10}
55	7.28×10^{-10}
60	8.67×10^{-10}
65	1.08×10^{-9}

The values in the table 2 depicts that the value of EMD increases with the increase in the temperature since the higher internal mass transfer process (liquid diffusion, vapor diffusion and capillary forces) occurs in the inner portion of the sample due to the higher transfer of heat. This taps the water from the interior to outer surface of the sample at the faster rate.

3.1.3 Activation Energy (E_a)

E_a is the energy consumed for drying the products at a particular condition. It was calculated based on the Arrhenius formula and E_a was derived from the slope of the plot derived from the data given in the Table 3.

Table 3 Effect of different temperature on E_a

Temperature (ºC)	E_a(kJ/mol)
45	27.28
50	26.27
55	25.40
60	24.72
65	23.81

The value of E_a decreased from 27.28 to 23.81kJ/mol while the temperature increased from 45ºC to 65ºC. At higher temperature the MOR and MRR increases with increased vapor pressure inside the sample which reduces the Ea than lower temperature.

3.1.4 Specific Energy Consumption (SEC)

SEC is to find the energy required to evaporate the one kg of water from the sample. The result obtained is depicted in Table 4.

Table 4 Effect of different temperature on SEC

Temperature (ºC)	SEC (kWh/kg)
45	63.42
50	59.37
55	54.08
60	51.07
65	48.35

Temperature increases with the decrease in the value of SEC from 63.42 to 48.35 kWh/kg of the sample. At higher temperatures, the specific heat of the air within the drying chamber accelerates the evaporation of moisture, requiring significantly less energy compared to lower temperatures.

3.2 Mathematical Modelling of Drying Data

The thin layer mathematical model was used to analyze the kinetics of drying irrespective of control mechanism. Fig 1 represents the normalized drying curves which were converted into the dry basis MCVs time to a dimensionless parameter known as MOR. The computation of curve fitting with the seven drying models with respect to drying temperature is shown in Table 5.

Table 5 Statistical Evaluation of Thin Layer Drying Models

Model	Temperature (ºC)	Estimated Parameter	R^2	SSE	RMSE
Page	45	k=0.0062;n=1.358	0.9837	0.0010	0.0088
	50	k=0.0087;n=1.501	0.9989	0.0002	0.0043
	55	k=0.0301;n=1.112	0.9976	0.0018	0.0165
	60	k=0.0538;n=1.362	0.9934	0.0004	0.0098
	65	k=0.1171;n=1.259	0.9904	0.0005	0.0113
Newton	45	k=0.0264	0.9627	0.0612	0.0620
	50	k=0.0453	0.9483	0.0560	0.0698
	55	k=0.0632	0.9804	0.0134	0.0364
	60	k=0.1045	0.9902	0.0107	0.0425
	65	k=0.1831	0.9824	0.0022	0.0197
Handerson	45	k=0.0385;a=1.027	0.9814	0.0423	0.0436

and Pabis	50	k=0.0531;a=1.057	0.9602	0.0378	0.0542
	55	k=0.0768;a=1.013	0.9947	0.0098	0.0328
	60	k=0.1352;a=1.002	0.9736	0.0085	0.0406
	65	k=0.1754;a=1.004	0.9807	0.0046	0.0198
Midilli et al.	45	K=0.0076;n=1.4453; a=0.9945; b=-0.0003	0.9999	0.0001	0.00411
	50	k=0.0093;n=1.5555; a=0.9987; b=-0.0001	0.9989	0.0003	0.00208
	55	k=0.0095;n=1.2173; a=0.6972; b=-0.0568	0.9878	0.0008	0.03804
	60	k=0.0533;n=1.3694; a=1.0021; b=0.0001	0.9999	0.0005	0.01147
	65	k=0.112;n=1.2871;a=1.0000; b=0.0002	0.9995	0.0004	0.0119
Logarithmic	45	k=0.0214;a=1.3341; c=-0.2734	0.9781	0.0102	0.0358
	50	k=0.0398;a=1.2146; c=-0.1737	0.9854	0.0098	0.0428
	55	k=0.0479;a=1.0145; c=-0.0874	0.9912	0.0057	0.0127
	60	k=0.1029;a=1.0537; c=-0.0379	0.9892	0.0072	0.0268
	65	k=0.1643;a=1.0124; c=-0.0097	0.9879	0.0035	0.0246
Modified Page	45	k=0.5424; n=0.5672	0.9992	0.0545	0.0654
	50	k=0.0215;n=0.6347	0.9974	0.0469	0.0745
	55	K=0.0231;n=0.4650	0.9953	0.0224	0.0562
	60	K=0.9756;n=0.0942	0.9985	0.0107	0.0378
	65	K=0.8456;n=0.0561	0.9964	0.0016	0.0264
Wang and Singh	45	a=-0.0212;b=0.00034	0.9837	0.0067	0.0211
	50	a=-0.0369;b=0.00029	0.9784	0.0135	0.0308
	55	a= -0.0457;b=0.00057	0.9924	0.0057	0.0227
	60	a=-0.0728;b=0.00212	0.9812	0.0170	0.0531
	65	a=-0.0098;b=0.00152	0.9436	0.0368	0.1041

From the results obtained it was found that the Midilli *et al.* model was best fitted very well when compared with other models. The non-linear regression analysis for the obtained data exhibited that Midilli *et al.* model had high R^2, lowest SSE and RMSE value than other models.

3.3 Physico-Chemical Properties (PCP)

3.3.1 Water Activity (a_w)

a_w plays a significant role in determining the life of the product. It is the ratio between the vapor pressure of the sample and pure water. a_w of dried sample at different temperature is shown in figure 3.

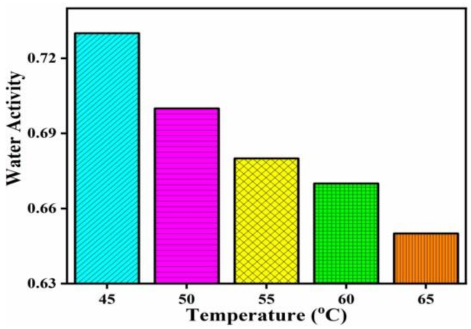


Figure 3 Effect of different temperature on a_w

The results obtained proved that the value of a_w decreases with increase in temperature. The high thermal effect caused by the higher temperature reduces the MC and a_w due to the increased surface area. Less water particles decrease the ability to react with microorganisms. MFSL was calculated based on the Man and Jones (2000) equation. The result obtained is given in Table 6. According to the findings, the minimum MFSL of fresh pulp was determined to be 12.76 days, while the maximum MFSL of dried pulp (441.57 days) was achieved by the sample dried at 65°C. Hence it was found that the temperature has significant effect on the reduction of a_w as well as enhances the shelf-life when compared with fresh pulp.

Table 6 MFSL of fresh and dried sample

Temperature (ºC)	MFSL (days)
Fresh	12.76
45	99.31
50	173.78
55	252.34
60	304.09
65	441.57

3.3.2 WAHC & OIHC

The results exhibited that, WAHC of dried powder was enhanced from 15.64 to 25.26 % with the increment in the temperature (figure 4). The cellular structure of the pulp was modified and makes the samples into spongy and fibrous (hydroxyl groups) which holds more amount water enhances the WAHC of the pulp (Deng *et al.* 2020).

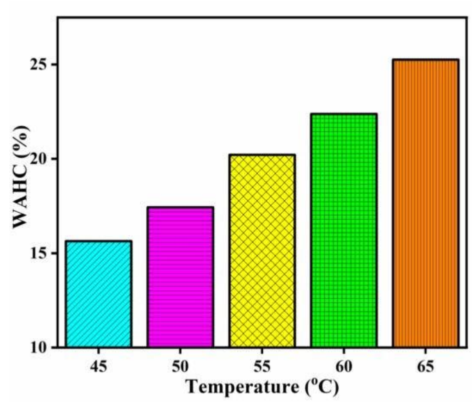


Figure 4 Effect of different temperature on WAHC

The highest OIHC value (figure 5) (20.09%) was attained for the pulp which was dried at the low temperature when compared with high temperature since at higher temperature the presence of carbohydrate and fibre are promoted which increases the polysaccharide and make the material into more hydrophilic. This reduces the absorption of hydrophobic nature of oil in the pulp.

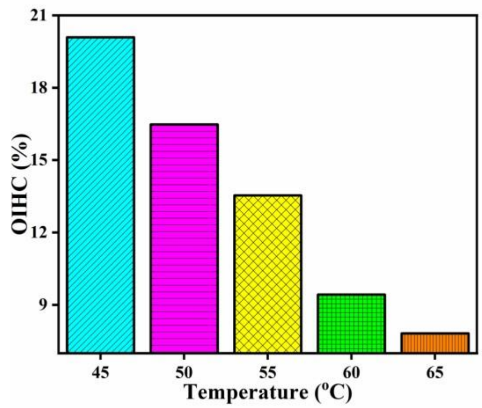


Figure 5 Effect of different temperature on OIHC

3.3.3 Swelling Capacity (SWC)

SWC represents the quantity of liquid absorbed by the sample, which determines its suitability for various applications in food processing. The SWC values of the dried pulp are illustrated in Figure 6.

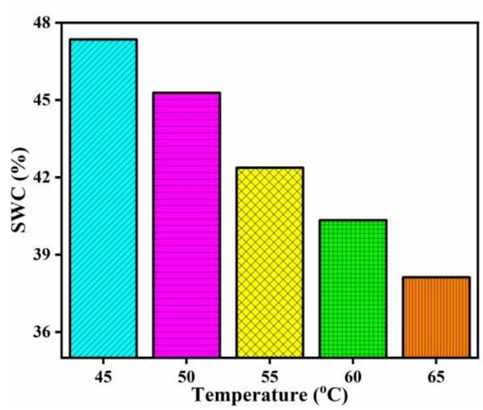


Figure 6 Effect of different temperature on SWC

From the results obtained it was found that the value of SWC decreased with increase in temperature. The SWC declined from 47.35% to 38.12% due to internal water evaporation, leading to a reduction in surface water and an increase in volumetric expansion, thereby causing the sample to undergo swelling. The presence of the hydroxyl groups in the sample at higher levels enhances the water binding capacity. Also the bonding of hydrogen between the water molecules and sample increases the value of SWC at low temperature (Jaisut *et al.* 2008).

3.3.4 Water Soluble Index (WSI)

WSI is used to estimate the amount of soluble compounds available in the sample. It is also used to evaluate the capacity of the soluble compounds to make a homogenous mixture and its dissolution power in the liquid. The WSI values of the dried pulp indicated in Figure 7.

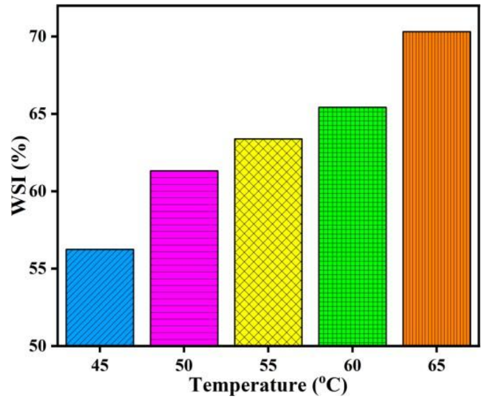


Figure 7 Effect of different temperature on WSI

From the figure, the WSI of the dried pulp increases along with the drying temperature (56.24 to 70.32 %). MC of the pulp dried at 65°C was less when compared with the pulp dried at low temperatures. Lower MC provides free flow final product with enlarged surface area. Higher surface area of the dried pulp promotes the hydration power and enhances the WSI. The structural damage occurring at higher temperature may also increase the WSI (Barajas *et al.* 2012).

3.3.5 Shrinkage Ratio (SHR)

SHR indicates the relationship of changes in volume with respect to drying temperature. SHR of dried pulp was analyzed and the results are represented in the Figure 8.

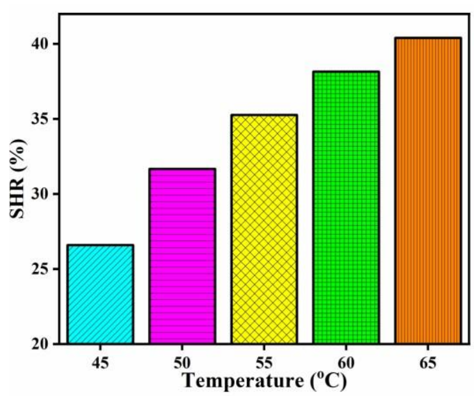


Figure 8 Effect of different temperature on SHR

Enhancement in drying temperature boosts the SHR value (26.59 to 40.41%) of the dried pulp sample. At higher temperature, the rate of drying increases which induce the high internal stress inside the tissue of the pulp producing the mechanical stabilization on the surface to reduce high quantity of liquid which increase the SHR value. Also high heat reduces the elasticity of the cell wall which in turn increases the SHR. (Malumba *et al.* 2010).

3.3.6 Rehydration Ratio (RR)

RR determines the structural damages that could occur during drying. The results were depicted in Figure 9.

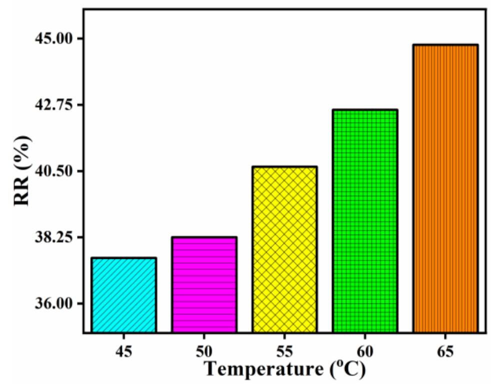


Figure 9 Effect of different temperature on RR

The RR value (37.55 to 44.77%) was increasing with the rise in drying temperature of the dried pulp sample. Transfer of heat was in higher rate while the temperature was increased. This ruptured the cell wall at a shorter period which makes it more porous in nature. This porosity allows the water to be absorbed and swells at faster rate, which enhances the value of RR (Abbasi *et al.* 2011).

3.4 Flowability Properties

3.4.1 Bulk Density (BD)

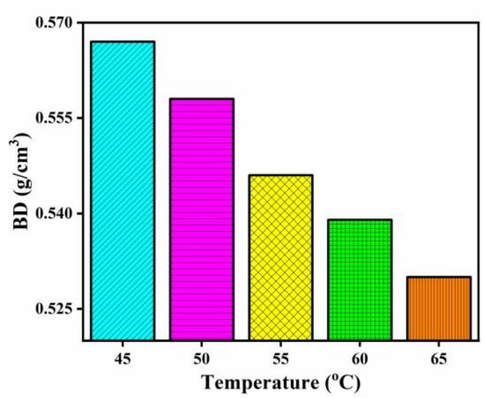


Figure 10 Effect of different temperature on BD

From the figure 10, it was observed that the highest BD value (0.567g/cm^3) was attained at the low temperature, drying rate was low and also moisture content of the final product was higher. Hence, presence of higher moisture in the dried product at lower temperature directed to enhance the void space inside the particle and augmented the BD value. Also, particle size of the product dried at low temperature was smaller which could reduce the inter-particle space and SHR value of the sample. Both could play a vital role and increases the BD value (Koc*et al.* 2008).

3.4.2 Tapped Density (TD)

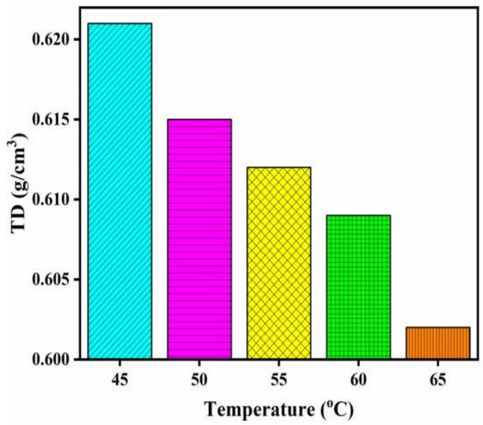


Figure 11 Effect of different temperature on TD

The results obtained were shown in figure 11 which depicts that at higher temperature, drying rate of the sample was high which cause diffusion of moisture from interior to external of sample at higher rate, trigger higher evaporation which decreases the moisture from the sample. Higher drying rate could have the capacity to make the product more shrunken. Hence, higher SHR value leads to produce the sample with larger particle size while grinding of the sample. Presence of larger particle size in the sample could direct to enhance the gaps between the large particles of the sample and reduced the TD value (0.602g/cm^3) (Koc *et al.* 2008).

3.4.3 Hausner Ratio (HAR)

HR is associated with the flow ability of any powder and it is one of the prime property of any powder which is utilized to finds its industrial application. Therefore, HAR value was computed from the BD and TD value and results were given in Figure 12.

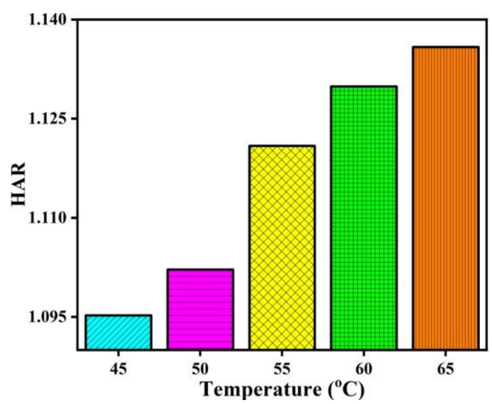


Figure 12 Effect of different temperature on HAR

The results exhibited in the figure 12shows that the HAR value (1.136) was slightly higher for the dried pulp powder at higher temperature than lower temperature. Because, BD and TD value was very close and it reflects in the slightly higher HR values. In addition, dried ber fruit pulp powder (high temperature) was having different size and uneven angular shape which was visualized during the experimentation of BD and TD and also the surface of dried powder was non-cohesive. Presence of different size of the powder, it occupies more void space, forms loose structure and low inter-particle adhesion force. During tapping, particles were flowed, difficult to stabilize, did not form a strong inter-particle structure and boost up the HAR value (Fitzpatrick 2013). Even though, dried pulp powder exhibited good flow ability activities based on HAR values which could be used as an ingredient in the preparation of food products.

2.4.4. Carr Index (CAI)

CAI is used to determine compressibility of any powder which is also derived from the BD and TD value obtained in this work. The outcome was exhibited in Figure 13.

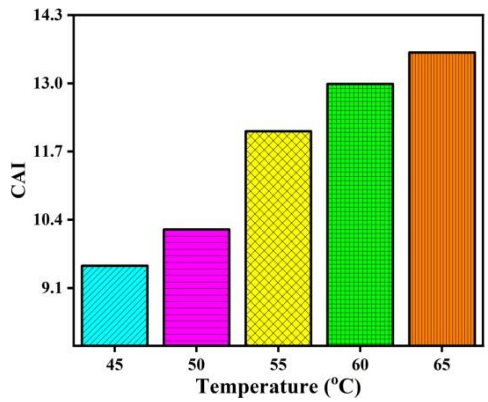


Figure 13 Effect of different temperature on CAI

CAI value of the dried pulp powder was found to be high at elevated temperature due to the lower a_w value of the sample obtained at high temperature. Higher a_w value of powder leads to increase the stickiness of the product, generate liquid bridges to form the capillary forces at the contact points of the particles and restrict the movement of the particle by binding with them. Development of difference forces (electrostatic, magnetic and Van Der Waals) involved in the flow behaviour of the powder was affected more resistance was created, prevent the powder to flow freely and reduced the CAI value (Fitzpatrick 2013). But, the obtained CAI value for all dried pulp exhibited the good compressibility and it can be used for bulk packing and storage.

3.4.5 Color Coordinates (CC)

CC is a most important parameter to evaluate the quality of fruits and vegetable based products. Hence, color indicators such as L, a and b value of fresh and L*, a* and b* value of dried pulp was determined using Hunter Calorimeter. It was found that the value of L* and b* was decreased from 81.25 to 48.62 and 1.12 to 1.01 while value of a* was enhanced from 42.22 to 47.85 when the temperature was increased (Figure 14). Calculated ΔE value was enhanced with the increment in temperature level which is due to the fact that, circulating air temperature was higher at higher temperature, that can initiate the oxidation reaction process, turned the white color into brown color of the pulp during drying and augmented the BI of the final product. The changes in the Hunter color values observed for the products dried at various temperatures (Figure 14) clearly indicate ΔE. Furthermore, a decrease in the L* value directly impacts the product's whiteness and reduces its WI (Figure 14). Loss of b* value directly reflects that, yellowness of the sample was increased due to the degradation of pigments, brown pigment formation and maillard reaction which also contributed to change the YI of the final product. In addition, C* value was incremented when the temperature was increased which is also evidently exhibited the enhancement of yellowness of the pulp. H* value of the sample was reduced when the pulp was subjected to higher temperature which indicates that, pulp does not lost their greenness color and didn't turned into orange-red in color (**Cao *et al.* 2016).**

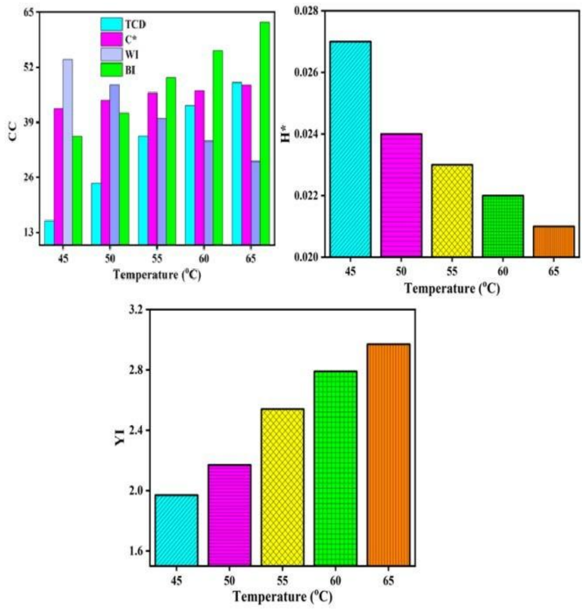


Figure 14 Effect of different temperature on CC

3.4.6 Hygroscopicity (HS)

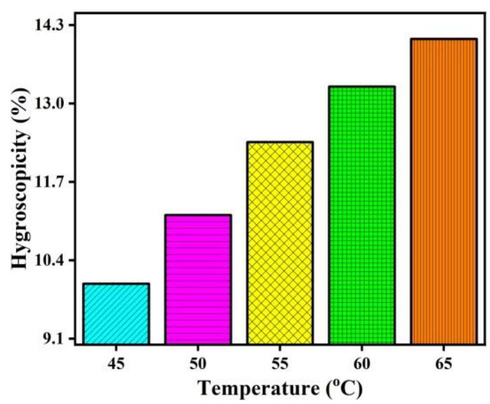


Figure 15 Effect of different temperature on Hygroscopicity (HS)

Dried pulp powder obtained at high temperature had low moisture content and contains more void space in their structure. Water present in the surrounding environment could diffuse in to the low moisture content pulp powder at the higher rate than the high moist pulp powder, attached to the hydrogen-bond present in the void space of the sample and trapped inside of the sample. Hence, more water was condensed in the sample; spread out the water throughout the sample and enhanced the HS value of the sample Molina *et al.* 2014 (Figure 15).

3.4.7 Degree of Caking (DC)

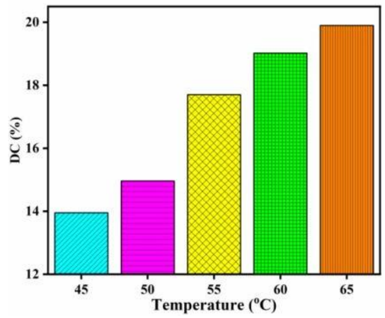


Figure 16 Effect of different temperature on DC

Lower DC value (13.95%) was obtained for the product derived from low temperature than high temperature (19.90%). Particle size of the pulp powder obtained at low temperature was very higher than high temperature. Particles with larger sizes exhibit reduced surface areas exposed to high humidity, resulting in lower water absorption from the environment and a decrease in the DC value. Conversely, powder obtained at higher temperatures (65°C) tends to have lower moisture content, facilitating water absorption from the environment onto the particle surfaces. This leads to the development of liquid bridges, formation of hydrogen bonds, transformation into agglomerated forms, and an increase in the DC value (Freeman et al., 2015), as illustrated in Figure 16.

3.5 Functional Properties

3.5.1 Total Phenolic Content (TPC)

Phenolics are naturally occurring compounds in the plant based food products which has more positive health effects to consumers. So, TPC of fresh and dried pulp was analysed and depicted in Figure 17

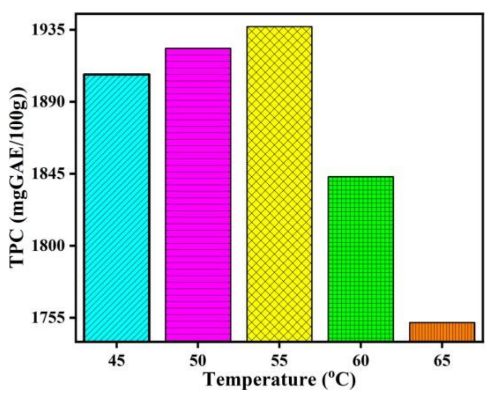


Figure 17 Effect of different temperature on TPC

Initially, fresh pulp contains 1896.40 mg GAE/100g of TPC. However, TPC of pulp was enhanced (1896.40 to 1937.01 mg GAE/100g) while increasing the temperature up to 55°C. During HAD, hot air was circulated inside the chamber of the oven as well as on the surroundings of the pulp. Hence, presence of heat in the chamber has the ability to penetrate in to the pulp through cell wall. Phenolics are mostly bounding on the cell wall of the plants through ester bonds. So, penetration of heat through the cell wall of plants leads to break the ester bond between phenolics and cell wall. Therefore, bounded phenolics in the cell wall were released from the cell wall and the TPC of the pulp was boosted up. TPC of pulp dried above the 55°C was reduced which is due to the fact that, phenolics are volatile compounds and heat sensitive (Sharma et al. 2015).

3.5.2 Total Flavonoid Content (TFC)

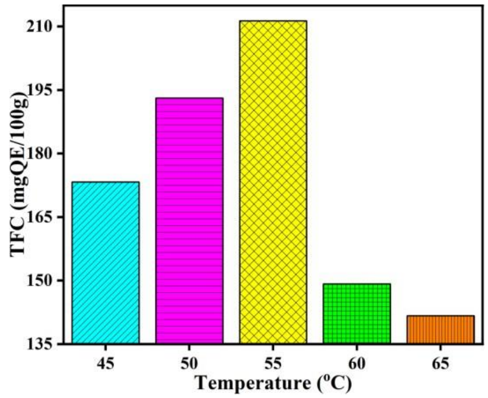


Figure 18 Effect of different temperature on TFC

Fresh pulp contains the TFC value of 157.05 mg QE/100g. When it was subjected to HAD (Figure 18), TFC of fresh pulp was increased up to 211.34 mg QE/100g at 55°C and after it was reduced to 65°C (141.67mgQE/100g). Increase in temperature from 45 to 55 ° C leads to prevent the exposure of the oxygen in the pulp which in turn reduce the degradation of the polyphenols present in the pulp and augmented the TFC of dried pulp. Moreover, in this temperature, bound phenols are released from the pulp due to the breakage of ester bond between cell wall and bound phenolics. This is also being a factor to enhance the TFC content of the dried pulp. Even though, after 55 °C, oxidation reaction took place due to the exposure of oxygen to the high temperature which could able to produce the orthoquinones from monophenols through hydroxylation and oxidation reaction and reduced the TFC of the dried pulp (Sharma et al. 2015).

3.5.3 Anioxidant Activity Assay

3.5.3.1 DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate)

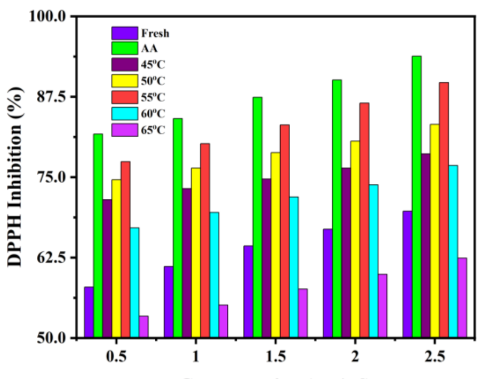


Figure 19 Effect of different temperature on DPPH

DPPH, a stable free radical, is commonly used as a tool to assess the antioxidant properties of compounds. The results obtained from this assessment are presented in Figure 19. It was observed that the DPPH Radical Scavenging Activity (RSA) increased from 77.4% to 89.7% at a concentration of 2.5 mg/ml. The scavenging effect of AA was found to increase with increasing sample concentration, ranging from 0.5 to 2.5 mg/mL. Particularly, at a concentration of 2.5 mg/mL, the scavenging activity was strongest at 55°C (Cherrat et al., 2018).

3.5.3.2 ABTS (2,2'-azino-bis 3-ethylbenzothiazoline-6-sulfonic acid)

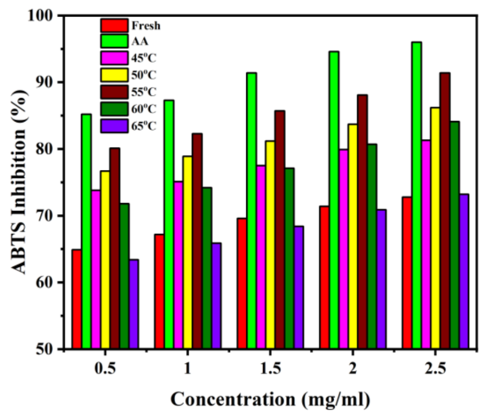


Figure 20 Effect of different temperature on ABTS

ABTS radical de-colorization assay was used to analyze the RSA of the fruit pulp sample, which was measured spectrophotometrically at 734 nm. The results obtained were depicted in the Figure 20.From the results it was observed that the value of ABTS increases gradually from 80.1 to 91.4% when the concentration increases from 0.5 to 2.5 (mg/mL). Decolorization of the solution happens due to the presence of hydrogen donating antioxidant ascorbic acid. The oxidizing agents in ABTS like potassium per sulphate and manganese dioxide increases the ABT radical. (Cherrat *et al.* 2018)

3.6 Optimization of HAD

Based on the drying characteristics, proximate analysis, physico- chemical and functional properties of the pulp, optimal condition was derived for the HAD. The optimal condition was found to be 55ºC and this temperature produces better quality of dried pulp than other temperature.

3. Conclusion

Based on the results obtained from this study, it is clear that Midilli model was found to be best fitted and this explains to understand the hot air drying kinetics of the apple ber fruit pulp powder. The results depicted that increase in temperature induces high stress that impacts the cell structure /cell wall and fibrous nature of the fruit pulp which increased the porosity, Hydrophilic, and Carbohydrates. These changes paved the way for enhance in WAHC, WSI, SHR and RR. However at high temperature, there is a decrement in moisture content changed the pulp in to hydrophobic nature which decreases the OIHC. Also, the surface area decreases with increases in the volumetric expansion of the sample which decreases the SWC. The densities (BD & TD) decreases with increase in temperature since the shrinkage lead to increase the particle size of the sample. Decrease in densities, increases the value of HAR and CAI. High temperature increases the yellowness of the sample due to the degradation of the pigment, formation of brown pigment and maillard reaction. Regarding functional properties, elevating the drying temperature initially enhances TPC and TFC values up to 55°C, after which they sharply decrease. This trend occurs due to the exposure of oxygen to the environment and the presence of volatile compounds in the sample, leading to the initiation of antioxidant activities. Among the temperatures used for drying the fruit pulp, it was found that the powder produced at 55^{o}C exhibited optimum results with least deterioration in the nutritional parameters. This study can further be extended to find the comparative analysis of various drying techniques and analyze the suitability for preparing new product with apple ber fruit powder.

Conflict of Interest:

The authors declare that they have no conflict of interest.

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