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Effect of microwave drying on drying and quality characteristics of banana chips

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Abstract
Banana chips were dehydrated using microwave energy at different power levels (20W, 40W, 60W and 80W). Dried samples were evaluated for drying parameters and quality attributes, viz. rehydration ratio, color, and microbial load. It was found that the increase in power level, decreases the drying time to react emc level. Minimum drying time of 19 min at 80W, whereas maximum drying time 45min was at 40W. Maximum Rehydration ratio was observed at 40W, lower Rehydration ratio was observed for both control and pretreated sample at 20W and 80W. The packaged (LDPE) banana chips was microbiologically safe upto 90 days in FSSAI norm. Page, Henderson and pabis, lewis, Wang sing, Peleg model more validated. Lowest RMSE value was observed in Peleg model followed by Lewis model. Pretreated sample shared lower L value (34.19, 30.07, 37.82, 45.82) than control sample (39.06, 28.88, 48.51, 47.17) whereas fresh banana (70.86) at 20W, 40W, 60W, 80W. Pretreated sample shared A value (7.39, 5.65, 5.91, 9.34) than control sample 7.28, 2.52, 10.33, 8.87) whereas fresh banana (4.56) at 20W, 40W, 60W, 80W. Pretreated sample shared lower B value (24.1, 21.66, 26.55, 30.14) than control sample (28.85, 15.08, 37.94, 36.99) whereas fresh banana (32.24) at 20W, 40W, 60W, 80W respectively.

Keywords: banana, microwave drying and drying models

1. Introduction
Banana (*Musa* spp.) is a major fruit crop in the tropics and they are popular for their flavor, texture and convenience value, being easy to peel and eat. Bananas is rich source of Vit A and C and B6 content of the diet, and are an important and immediate source of energy often eaten by sports people during competitions. They are also cholesterol free and high in fiber. A medium sized banana contains 280kJ. Now a day's banana farming has tremendous increase hence its post-harvest practices are improving day to day.

Now a days research focus and interest on banana in recent time has tremendous increase hence its post-harvest practices are improving day to day. The products gain maximum return dried by solar or mechanical methods are often poor in colour, flavor (taste and aroma), texture and rehydration qualities. Case hardening (the formation of hard outer shell) and shrinkage are also two major problems with conventional drying processes. In recent years, improvement of quality retention by dried products (rehydrability etc.), by altering process conditions and/or pre-treatment's, has been a major research goal.

The use of microwaves in drying of fruits has increased in the last few decades, mainly due to more accurate process control, good MW penetration into fruit tissues and shorter processing times. Microwave drying provide low process temperatures and faster water evaporation, offering shorter drying times and higher quality of dried product compared to other drying methods. The role of microwaves is to heat the water molecules in the product and these molecules migrate from the interior to the surface of the product, whereas hot air is supposed to remove free water at the surface (Sanga *et al.*, 2000) [8].

However, the microwave drying process can have very high costs. Several studies have shown that using pre-treatment's prior to microwave-drying could decrease drying time and thus drying costs. Osmotic dehydration seems to be an efficient way to remove up to 50% of initial moisture.

The microwave energy was used to dehydrate banana slices and to analyse its impact on quality and drying attributes of banana slices.

2. Materials and Methods
2.1 Procurement of Raw Material
Fresh banana was procured from the local market of Allahabad city. It was ensured that the fruits have good physiological maturity as well as none kind of damage and infestation.

2.2 Primary processing and sample preparation

Banana was washed, sliced (approx 3 mm thickness) and osmoticaly dehydrated in sugar solution (70° Brix). Microwave oven was used for the drying of banana chips. After drying the sample was packed and stored at room temperature for further analysis. The treatment, type and range of processing parameters and characteristics used for evaluating phenomena of drying and quality of product are given in detail in Table 1.

Table 1: Detail of variables/parameters, their level and description

S. No	Parameter	Level	Description	Quality parameters
1	Thickness of Banana chips	1	Uniform Size	Moisture content, Drying rate, Rehydration ratio, color, Microbial, Drying kinetics
2	Pretreatment	1	Control and osmotic dehydration	
3	Microwave power	4	20W, 40W, 60W and 80W	
4	Packaging	1	LDPE	

2.2.1 Process for dehydration of banana chips

Banana
↓
Peeling
↓
Slicing (thickness 3mm)
↓
Pretreatment (Osmostic)
↓
Microwave drying (20, 40, 60, 80) Watt
↓
Packaging
↓
Storage

2.5 Microwave drying

The pretreated banana chips were dried in microwave oven shown in Fig 1. Drying was carried out at different microwave power 20, 40, 60 and 80W. The sample of banana chips design was dried simultaneously, in order to ensure uniform drying conditions. After the dried banana chips were analyzed for different physicochemical analysis.

2.6 Physicochemical Analysis

2.6.1 Determination of moisture content

AOAC-Method was used to determine the moisture content of banana chips samples

Procedure

The instrument used for moisture determination was hot air oven shown in Fig. 2. 5g of the prepared sample was weighed and taken in the moisture dish. Placed the dish in the oven maintained at the 110±5 ºC for overnight. Cooling in the desiccators was done and weighted.

$$\text{Percent moisture content} = \frac{\text{Loss in weight}}{\text{Initial weight of sample}} \text{ X } 100$$

The moisture content for the sample was computed using the following equations.

$$\text{Moisture content (wet basis)} = \frac{M_1 - M_2}{M_1} \text{ X } 100$$

$$\text{Moisture content (dry basis)} = \frac{\text{M. C. (wet basis)}}{100 - \text{M. C. (wet basis)}} \text{ X } 100$$

$$\text{Rate of drying} = \frac{\text{M. C. lost}}{\text{Time difference}}$$

Where,
M.C. = moisture content of sample (% w.b. and d.b.)
M_1 = wt of sample before oven drying (g)
M_2 = wt of sample after oven drying (g)

2.6.3 Determination of Drying rate (DR)

Drying rate is the loss of moisture from the wet solid per each unit of time.

$$\text{Drying rate} = \frac{\text{Amount of moisture removed(g)}}{\text{Time taken (min)}}$$

2.6.4 Rehydration Ratio

5 g of dehydrated sample was taken into a small container and 120 ml of distilled water added to it. Cover the container with a watch glass and boil the water. Boil the water gently for 15 minutes. Turn out the sample onto a white dish and cover the surface with a piece of filter paper to soak the excess water and recorded the weight of the sample. Rehydration ratio was calculate by the following formula

$$\text{Rehydration ratio } \frac{B}{A}$$

Where,
B = weight of sample (g) after rehydration
A = weight of sample (g) before rehydration

2.6.5 Color Determination

Principle

Three elements are necessary to see color: a light source, an object, and an observer. A light source emits light that appears white, but when diffracted by a prism, represents all wavelengths in the visible light spectrum (400-700 nm). Colorimeters use illuminants, which are plots of relative energy versus wavelengths, to represent different light sources under standardized and quantifiable conditions. Objects, or samples, modify light differently, depending on the colorants (ex. dyes, pigments) that are present, by selectively absorbing some wavelengths, while reflecting or transmitting others. The amount of light reflected or transmitted can be quantified to form a spectral curve of the object's color characteristics. Finally, observer functions have been established using red, blue, and green glass filters, to simulate the cone-shaped receptors in the human eye, and to quantify numerically the way in which the average human observer perceives color. Three-dimensional scales, such as CIE L*a*b*, have been developed to objectively quantify color values. This scale defines color as follows:

L* (lightness) axis: black to white (0 to 100)
a* (red - green) axis: positive values are red; negative values are green; 0 is neutral
b* (yellow-blue) axis: positive values are yellow; negative values are blue; 0 is neutral

All visible colors can be quantified within this 3-D rectangular space. Color differences may be expressed relative to a standard, such as a color tile, or may be expressed relative to other samples tested under uniform conditions. Sample uniformity is critical to the measurement. Readings may be affected by chalk, hulls or other interferences, and should be minimized when conducting color analysis.

2.10 Drying models

Simplified drying models have been used to quantify drying kinetics of various fruits and vegetables. The experimental drying data for banana chips were fitted to the exponential thin layer drying models as shown in Table 2 by using non-linear regression analysis. Regression analyses were performed using MS Excel 2007.

Table 2: Thin layer drying models

Model name	Model
Page	MR = exp (-kt^N)
Lewis	MR = exp (-kt)
Henderson and pabis	MR = a exp (-kt)
Wang singh	MR = 1+ at + bt^2
Peleg	MR = 1- t/(a + bt)

The moisture ratio (MR) can be calculated as

$$MR = \frac{M - Me}{M_i - M_e}$$

Where,
MR = Moisture content or moisture ratio
M = Moisture at any time t during drying
M_i = Initial moisture content
M_e = Equilibrium moisture content

The goodness of fit for each model was evaluated based on root mean square error (RMSE), chi square (χ^2), and relative percent error (PE). The predicted moisture ratio was compared to the experimental moisture ratio using root mean square error and chi square as shown in the following equations (McMinn, 2006):

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{n}(MR_{exp,i} - MR_{predicted,i})\right]^{\frac{1}{2}}$$

$$\chi^2 = \frac{1}{N-n}\sum\nolimits_{i=1}^{n}(MR_{exp,i} - MR_{predicted,i})^2)$$

As RMSE and χ^2 approach zero, the closer the prediction is to experimental data. Where RMSE and χ^2 compare the differences between the predicted moisture ratios to the experimental moisture ratios, relative percent error compares the absolute differences between the predicted moisture contents with the experimental moisture contents throughout drying (McLaughlin and Magee, 1998; Ozdemir and Devres, 1999):

$$PE = \frac{100}{N}\sum\nolimits_{i=1}^{n}\frac{\left|M_{exp,i} - M_{predicted,i}\right|}{M_{exp,i}}$$

The relative percent errors below 10% indicate good fit.
The coefficient of determination (R^2) was one of the primary criteria to select the best model to compare with experimental data. In addition to R^2, root mean square error (RMSE) was used to compare the relative goodness of the fit. The best model describing the drying behaviour of banana was chosen as the one with the highest coefficient of determination and the least root mean square error.

3. Results and Discussion

The Fresh banana contains approx 68 ± 2% moisture. The pre-treated banana chips were dried in Microwave oven at different power level to reduce the moisture content. The relationship between moisture content and drying time as affected by pre-treatment and power is shown in Fig. 3. On critical evaluation of Fig.3 it was revealed that there was sharp decrease in moisture content as the microwave power increased also resulting in lower drying time than at low microwave power.
The banana chips were placed into concentrated solutions of soluble solids having higher osmotic pressure were caused by the water and solute activity gradients across the cell membrane, the cell wall and the surface of the tissue. The complex cellular structure of banana acts as a semi-permeable surface. Since these compartments are only partially selective, there is always some solute diffusion into the food. Results obtained showed that the osmotic dehydration of banana chips affects the drying time. The osmotic dehydrated chips were found to have more moisture removal as compared to control chips. The moisture content at each time interval was measured through mass balance and wet basis moisture content of control and pretreated banana chips was calculated and given in table A1 and A2 respectively. The osmotic dehydrated samples at 60 and 80 watt took less time for removal of moisture than other sample. At 20 watt the moisture content of control sample was decreased from 70% (w.b) to 3.60% (w.b) in 45 min whereas the osmotically dehydrated sample attains lower moisture from 35.96% (w.b) to 2.36% in 28 min. At 40 watt the moisture content of control sample was decreased from 70% (w.b) to 2.81% (w.b) in 33 min whereas the osmotically dehydrated sample attains lower moisture from 36.8% (w.b) to 0.64% in 14 min. At 60 watt the moisture content of control sample was decreased from 70.5% (w.b) to 1.66% (w.b) in 19 min whereas the osmotically dehydrated sample attains lower moisture from 35.5% (w.b) to 1.02% in 11 min. At 80 watt the moisture content of control sample was decreased from 70.9% (w.b) to 2.17% (w.b) in 18 min whereas the osmotically dehydrated sample attains lower moisture from 35.78% (w.b) to 0.89% in 10 min which shows that because of osmosis the banana cells were able to lose more moisture than control.
The experimental data as the moisture ratio (MR) versus drying time were fitted to the five exponential thin layer drying models, as shown in Table 3 to Table 4. Table 5 to Table 6 shows the results of the regression analysis performed on the drying data. Regression analyses were performed using MS Excel 2007. The model that best described the thin layer drying kinetics is the one that gives the highest R^2 and the lowest RMSE and PE values. Based on these criteria, the Lewis's model proved to be an overall better prediction model for drying of banana. The observed analysis shows that the Lewis model obtained the highest value for the coefficient of regression (R^2) and the least value for the reduced chi-square ($\chi 2$) and RMSE when compared with the other models.

Table 3: Emperical Constant and model prediction evaluation of Page model

Power level	K (min^{-1})	N	R^2	RMSE	χ^2	PE%
20W (Control)	1.546	0.106	0.851	0.366606	0.526621	4.013776
40W (Control)	1.64	0.252	0.928	0.672309	3.489423	10.83229
60W (Control)	1.473	0.326	0.948	0.845328	6.811201	6.491367
80W (Control)	1.069	0.297	0.920	0.733178	3.709364	7.251849
20W (Pre-treated)	1.513	0.113	0.856	0.36847	0.558599	7.008957
40W (Pre-treated)	1.345	0.136	0.849	0.433094	0.816598	4.7167
60W (Pre-treated)	0.879	0.176	0.843	0.513098	1.19047	6.448414
80W (Pre-treated)	0.855	0.166	0.879	0.503597	1.099313	5.20093

Table 4: Emperical Constant and model prediction evaluation of Lewis model

Power Level	K (min^{-1})	R^2	RMSE	χ^2	PE%
20W (Control)	0.089	0.999	0.020863	8.55577E-06	0.104
40W (Control)	0.305	0.963	0.09373	0.00161	2.86683
60W (Control)	0.398	0.982	0.10517	0.00182	3.6543
80W (Control)	0.446	0.991	0.07865	0.00066	2.55078
20W (Pre-treated)	0.114	0.989	0.03837	0.00011	0.41701
40W (Pre-treated)	0.138	0.997	0.02342	1.63917E-05	0.1339
60W (Pre-treated)	0.249	0.990	0.02739	3.06089E-05	0.59804
80W (Pre-treated)	0.231	0.998	0.03406	3.71965E-05	0.50284

Table 5: Emperical Constant and model prediction evaluation of Henderson and Pabis model

Power Level	K ($min^{-1)}$	A	R^2	RMSE	χ^2	PE%
20W (Control)	0.089	0.033	0.999	0.119516	0.097286	3.846
40W (Control)	0.305	0.495	0.963	0.130408	0.007209	5.303
60W (Control)	0.398	0.411	0.982	0.159756	0.11988	8.046
80W (Control)	0.446	0.268	0.991	0.148235	0.010494	8.816
20W (Pre-treated)	0.114	0.126	0.989	0.104612	0.005776	3.289
40W (Pre-treated)	0.138	0.031	0.997	0.126029	0.00887	4.849
60W (Pre-treated)	0.249	0.076	0.990	0.134426	0.010502	7.731
80W (Pre-treated)	0.231	0.062	0.998	0.13737	0.01029	7.616

Table 6: Emperical Constant and model prediction evaluation of wang singh model

Power Level	K (min^{-1})	R^2	RMSE	χ^2	PE%
20W (Control)	0.089	0.059	0.032163	6.44587E-05	0.117
40W (Control)	0.305	0.863	0.04572	0.00067	2.69963
60W (Control)	0.398	0.782	0.20717	0.00115	3.5783
80W (Control)	0.446	0.791	0.05545	0.00246	2.44078
20W (Pre-treated)	0.114	0.789	0.04837	0.00211	0.58014
40W (Pre-treated)	0.138	0.787	0.03452	1.55847E-05	0.02589
60W (Pre-treated)	0.249	0.770	0.01479	3.04087E-05	0.478304
80W (Pre-treated)	0.231	0.778	0.04504	3.68741E-05	0.401259

Table 7: Emperical Constant and model prediction evaluation of peleg model

Power Level	K (min^{-1})	R^2	RMSE	χ^2	PE%
20W (Control)	0.089	0.069	0.041287	5.33145E-08	0.128
40W (Control)	0.305	0.887	0.03481	0.00058	2.74458
60W (Control)	0.398	0.697	0.30855	0.00145	3.6578
80W (Control)	0.446	0.650	0.06694	0.00369	2.58741
20W (Pre-treated)	0.114	0.698	0.07414	0.00278	0.44012
40W (Pre-treated)	0.138	0.669	0.02365	2.24584E-05	0.03547
60W (Pre-treated)	0.249	0.560	0.02457	3.04044E-07	0.589402
80W (Pre-treated)	0.231	0.580	0.05503	3.45879E-07	0.354126

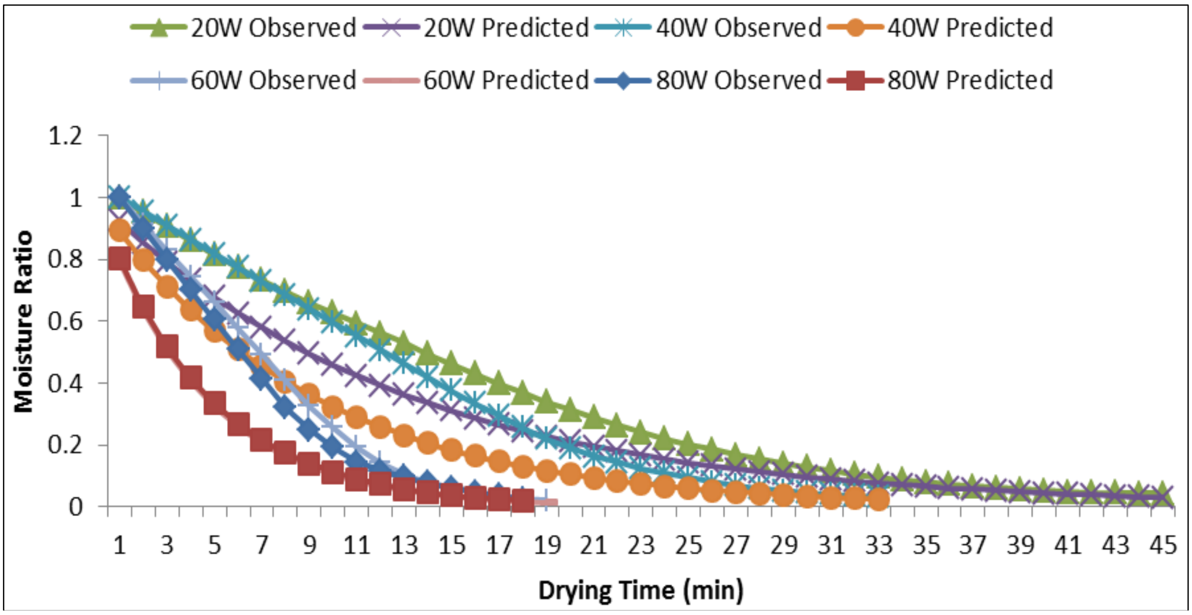

Fig 1: Comparison between the Predicted and Experimental Data of pre-treated samples Based on Lewis Model

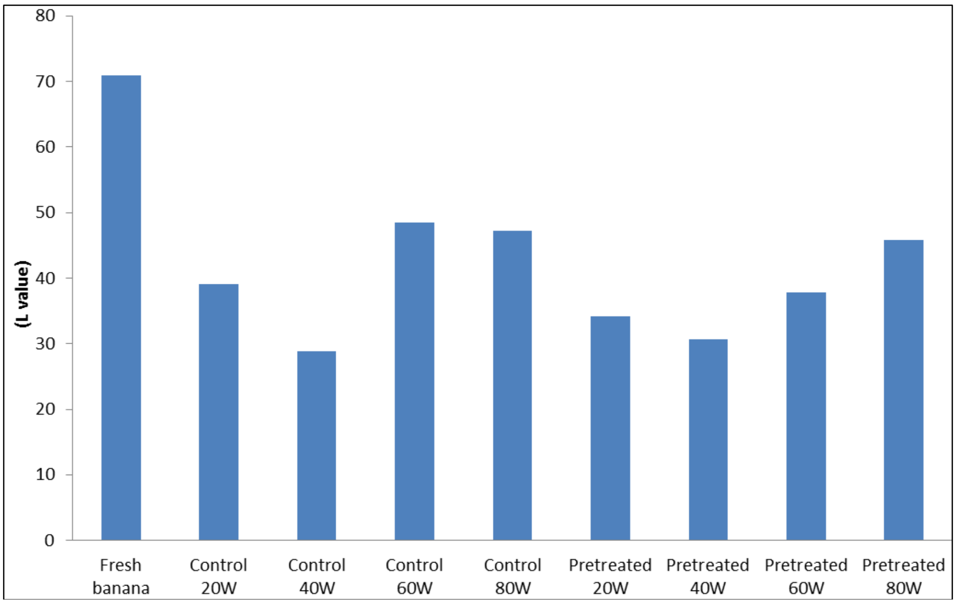

Fig 2: Effect of microwave drying on L* value of banana chips

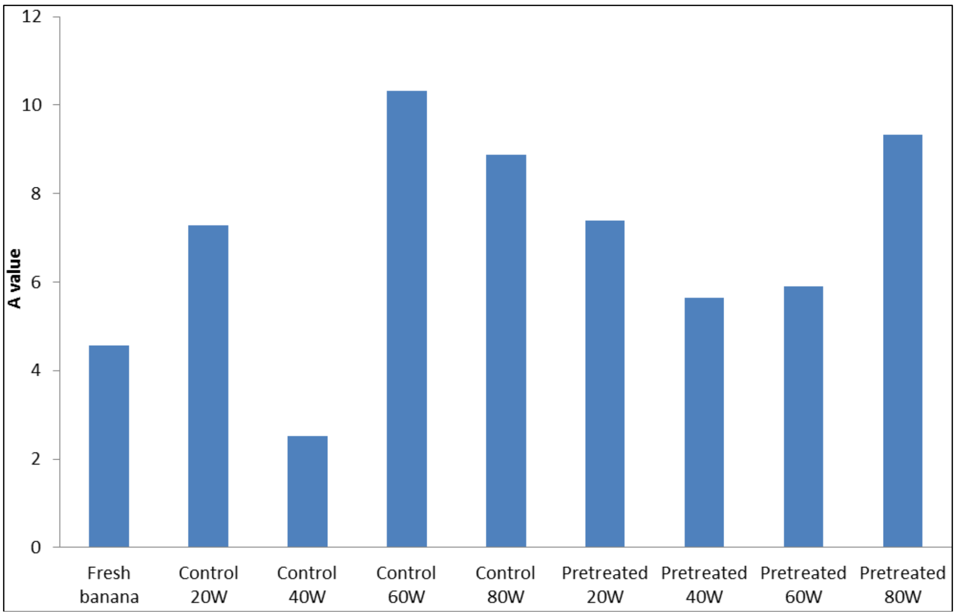

Fig 3: Effect of microwave drying on a* value of banana chips

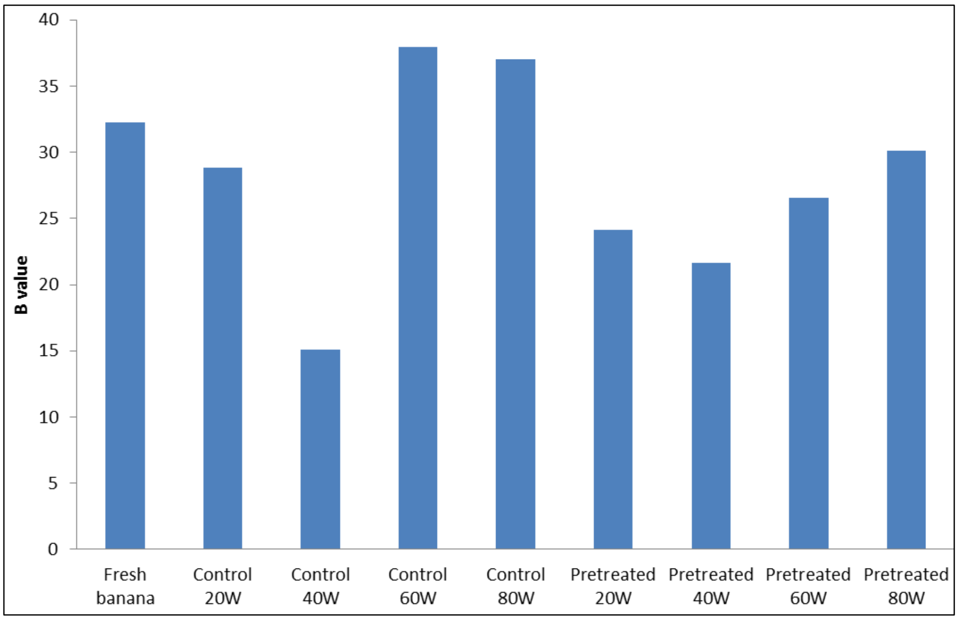

Fig 4: Effect of microwave drying on b* value of banana chips

4. Conclusion

The study concludes that the pretreated samples were found to have more moisture removal in less time as compared to control sample. The growth of bacteria are found on 60 and 90^{th} day in the entire control sample and on 90^{th} day in the entire pre-treated sample**.** According to the thin layer drying kinetics criteria, the observed analysis shows that the Lewis model obtained the highest value for the coefficient of determination (R^2) and the least value for the reduced chi-square ($\chi2$) and RMSE when compared with the Henderson-pabis and Page model.

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