ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE June 2023. Vol. 19(2):211-218
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

EFFECT OF DRYING CONDITIONS ON THE DRYING KINETICS AND COLOUR CHANGES OF PLANTAIN (MUSA X PARADISIACA) SLICES USING COMBINED HEATED AIR AND INFRARED DRYERS

W. A. Olosunde[1]*, M. M. Akpanesen[1], U. E. Assian[1] and O. O. Olosunde[2]

[1]*Department of Agricultural and Food Engineering, Faculty of Engineering, University of Uyo, Uyo.*
[2]*Department of Food Science and Technology, Osun State Polytechnic, Iree, Nigeria.*
**Corresponding author's email address: williamolosunde@uniuyo.edu.ng*

ARTICLE INFORMATION

Submitted 16 December, 2022
Revised 28 February, 2023
Accepted 6 March, 2023

Keywords:
Drying kinetics
infrared intensity
heated air drying
colour change
moisture content
plantain slices

ABSTRACT

Most agricultural crops with high moisture content are difficult to preserve. The most common method of preservation is drying. Thus, drying operation where a combination of two or more modes is used, could speed-up drying process. However, the scalability of combined heated air and infrared drying (CHAID) for rural consumers have not been investigated. This study was conducted to examine the effect of drying conditions (temperature and infrared intensity) on the drying kinetics and total colour changes (ΔE) of plantain slices using a CHAID dryer. Matured unripe plantain samples were sourced from a market, peeled, washed in running water and then sliced into 4 × 20 × 20 mm dimension. Initial moisture content (MC_i) determined using oven drying method. 2.0 g of the sliced sample were weighed and dried in a combined heated air and infrared dryer (IR) operated at 800 W/m^2 alone till the mass (bone dry mass) did not vary after repeated weighing. Also, samples ΔE was monitored using colorimeter within the drying period. The same procedure was repeated using heated air-drying mode (HAD) operated at 65 ± 2 °C; IR-800 W/m^2 plus HAD at 65 ± 2 °C, and IR-1000 W/m^2 plus HAD at 65 ± 2 °C. The moisture content (MC) and drying rate were computed from duplicate data using Microsoft Excel programme. The variation of % MC with drying time, drying rate against MC and ΔE versus drying time were made and ΔE compared using Tukey Honest Significant Difference. Results showed that the samples' MC_i by oven dried method was 55.84%wb whereas those dried using IR-800 W/m^2 alone, HAD (65 ± 2 °C) alone, IR-800 W/m^2 plus HAD (65 ± 2 °C) and IR-1000 W/m^2 plus HAD (65 ± 2 °C) modes were 57.43, 52.13, 57.41 and 57.03% wb, respectively, and their corresponding critical or equilibrium moisture content were 5.62, 5.03, 12.45 and 5.95%wb, respectively. Similarly, a shortest drying time (30 mins) and minimal total colour changes (ΔE = 12.42) were found when IR (1000 W/m^2) plus HAD (65 ± 2 °C) was used. It also observed that, plantain slices dried using HAD (65 ± 2 °C) mode showed statistically significant mean difference in ΔE when compared with other three drying modes within 10 to 30 minutes drying time. Since, IR (1000 W/m^2) plus HAD (65 ± 2 °C) mode gave shortest drying time and minimal ΔE, it is recommended for use in drying plantain slices by restaurant, hotels operators and food processors .

1.0 Introduction

Drying is a mass transfer process in which heat is applied to remove water or another liquid by evaporation from a liquid, semi-solid or solid phase (Farlex, 2011). The final dried product may be solid, in the form of particles (corn flakes or cereal grains) or powder (Farlex, 2011). In bioproducts like grains, processed food, and pharmaceuticals such as vaccines, the solvent which is usually removed is water. The heat source in most cases could be heated air, infrared (IR). Heated air used convective drying method comprises of hot air where its temperature is increased, thereby inducing quick heat transfer for fast drying process. It also decreases air relative humidity, and increases the driving force for drying (Onwude *et al.*, 2016). However, the application of IR heating in post-harvest and food processing has shown more popularity in recent time, because of its advantage over other conventional heating methods. The method is faster and has efficient heat transfer. It also produces uniform product heating, lowers processing cost and better organoleptic and nutritive value of the processed food (Perera and Rahman, 1997; Andrés *et al* 2007; Vishwanathan *et al.,* 2010; Moses *et al.*, 2014; Zhang *et al.,* 2017). It has been used in roasting, baking, thermal treatments (pasteurization, blanching, sterilization) and drying of foods (Sandu, 1986).

IR drying or heating involves heat transfer by radiation between a hot element and a material at lower temperature that needs to be dried**.** The highest wavelength of the radiation is dependent on the temperature of the heated element (Kathiravan *et al.*, 2008). In general, infrared radiation is grouped into 3 main categories, in terms of peak wavelength peak of the radiation: (i) Short-wave IR (SW): from 0.78 μm to 2 μm; (ii) Medium-wave IR (MW): from 2 μm to 4 μm; (iii) Long-wave IR (LW): from 4 μm to 1000 μm. Commonly, most agricultural crops have high moisture content, thus could be resourcefully dried by using combination of two or more approaches. This offers the synergistic influence while retaining material quality. For instance, during combined IR and heated air drying, the fast heating of food materials by IR radiation (due to high heat intensity and penetration depth) quickens the rate of moisture movement towards the material's surface (Onwude *et al.,* 2016), while the convective air- flow guarantees the quick removal of moistness from the surface thus sustaining the moisture gradient (driving force). However, the scalability of combined heated air and infrared drying for rural consumers appears not to have been investigated, neither does a report exist on its application to the drying of plantain slices. Therefore, the main objective of this study was to examine the effect of drying conditions (temperature and infrared intensity) on the drying kinetics and colour changes of plantain slices using a combined heated air and infrared dryer.

2. Materials and Methods

2.1 Sample Sourcing and Preparation

Two bunches of matured unripe plantain samples were purchased locally at Ikot Okubo Market, Uyo, Akwa Ibom State, Nigeria. Samples at the same maturity stage, shape, size and weight were chosen in order to reduce the variability and improve the accuracy of the results. The samples were peeled, washed in running water and sliced into 4 × 20 × 20 mm dimension using a slicer and Vernier calliper.

2.2 Moisture Content Determination

The moisture content of the fresh four (4) sliced samples was determined using the standard hot air oven method (ASAE, 2005) and Equation 1.

$$MC_{wb} = \frac{(W_2 - W_{1\_}) - (W_3 - W_{1\_})}{(W_3 - W_{1\_})} \times 100 \quad (1)$$

where, W_1 = weight of empty can (g), W_2 = weight of can + sample before oven drying (g) and W_3 = weight of can + sample after drying (g).

2.3 Drying Methods

About 2 g of sliced plantain samples was weighed using digital weighing balance and dried in a combined heated air and infrared dryer operated at infrared heat intensity of 800 W/m^2 alone (IR-800 W/m^2) at drying time interval of 10 minutes. At this duration, the samples were removed, cooled in a desiccator for 5 minutes, and thereafter re-weighed using digital weighing balance. The experiment was repeated with the drying samples until there was no significant weight loss in the sample was observed. This weight attained is regarded as bone dry mass. Meanwhile, the infrared heat intensity was measured using solarimeter (Md- Fahim, 2019). Also, the initial total colour change (ΔE) of the fresh plantain slices, based on lightness value (L*), redness or greenness (a*) and yellowness values (b*) dried under this mode was read using colorimeter (Vernier Science Education, 2020). At the same drying time interval of 10 minutes, the samples ΔE were read and noted until bone dry mass was attained. The experimental run was conducted in duplicates. The same procedure was repeated using heated air-drying mode (HAD) operated at 65 ± 2 °C; IR-800 W/m^2 plus HAD at 65 ± 2 °C, and IR-1000 W/m^2 plus HAD at 65 ± 2 °C. The moisture content was calculated using Equation 1. However, the drying rate also computed using Equation 2.

$$\text{Drying rate} = \frac{\text{Amount of water removed (g)}}{\text{Drying time used (min)}} = \frac{dw}{dt} \qquad (2)$$

Then, the plots of moisture content (MC) against drying time and drying rate versus MC of the dried plantain slices obtained in each drying mode were made. Also, the variation of total colour change (ΔE) observed in each drying mode was made against drying time. Comparison of ΔE of the samples dried under the four modes within 10 to 30 minutes drying time was made using Tukey Honest Significant Difference at 5% level of probability. Drying mode with minimum ΔE and shortest drying time was noted as the best drying mode.

2.4 Statistical Analysis

Data were collected in duplicate. Microsoft Excel programme was used in computing their mean values presenting the findings of the study.

3.0 RESULTS AND DISCUSSION

3.1 Moisture Content and Drying Rate of the Dried Samples

The initial MC of fresh plantain slices determined by oven drying method was 55.84%wb. The plot of MC (% wb) of plantain slices using at various drying modes against drying time is depicted in Figures 1.

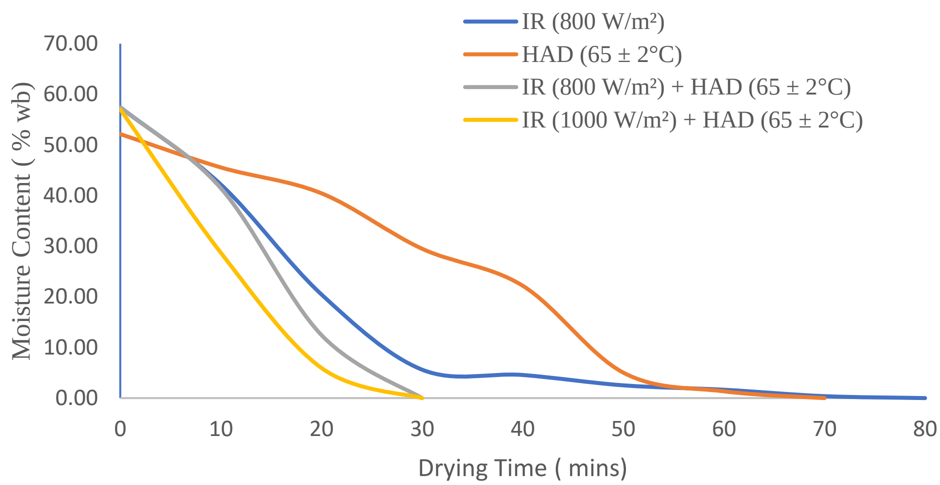

Figure 1: Variation of moisture content (% w.b.) with drying time of plantain slices using various drying modes

Figure 1 shows MC of the sample decreased with increased in drying time. Longer period of drying generates more heat energy required for drying process. Initial MC of the samples dried using IR-800 W/m^2 alone, HAD (65 ± 2 °C) alone, IR-800 W/m^2 plus HAD (65 ± 2 °C) and IR-1000 W/m^2 plus HAD (65 ± 2 °C) were 57.43, 52.13, 57.41 and 57.03% wb, respectively. It took IR-800 W/m^2 plus HAD (65 ± 2 °C) and IR-1000 W/m^2 plus HAD (65 ± 2 °C) drying modes 30 minutes to completely remove evaporable water away from the samples whereas IR-800 W/m^2 alone and HAD (65 ± 2 °C) alone used 70 and 80 minutes, respectively. Shorter drying period was a result of the combined drying modes (IR and HAD) which generated more energy per period. The samples MC is perceived to be slightly more than half of the sample mass. Besides, it could also be observed that IR-800 W/m^2 plus HAD (65 ± 2 °C) and IR-1000 W/m^2 plus HAD (65 ± 2 °C) are energy intensive modes.

The variation of drying rate with moisture content is presented in Figure 2.

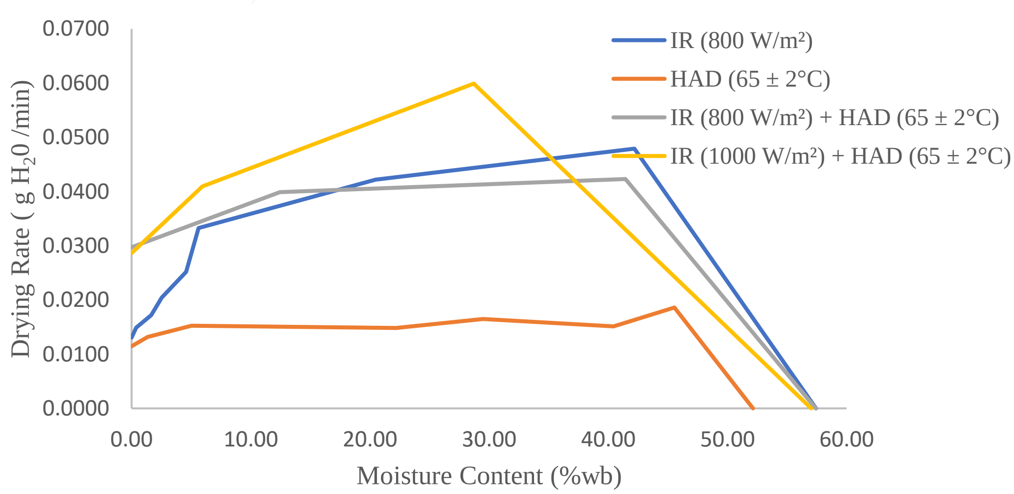

Figure 2: Variation of drying rate with drying time of plantain slices using various drying modes

From Figure 2, it can be seen that the plots had rising, constant and falling rate periods. Samples dried using IR-800 W/m^2 alone showed gradual decreased in drying rate between 42.18 to 5.62%wb. It equilibrium moisture content (EMC) or critical moisture content (CM) was 5.62%wb and at this period, 0.0332 g H_20 / min as drying rate was evaporated. Also, the drying rate of sample dried using IR-1000 W/m^2 plus HAD (65 ± 2 °C) mode rapidly declined between 28.71 to 5.95%wb (as EMC= CM). At 5.95%wb, 0.041 g H_20 / min was evaporated. Whereas samples dried using IR-800 W/m^2 plus HAD (65 ± 2 °C) and HAD (65 ± 2 °C) alone recorded constant rate periods between 41.45 to 12.45%wb and 40.45 to 5.035wb, respectively. Their EMC and CM was 12.45 and 5.03 %wb, respectively. The amounts of water removed per min at these periods were 0.0339 and 0.0153 g H_20 / min, respectively. However, during constant rate period, there is a continuous migration of water molecules from interior part of the sample matrices at constant rate which form film of water on the sample surface which later evaporates away as drying time increases. The sample MC at this phase is at equilibrium (EMC) with the partial pressure of water vapour in the drying chamber. Furthermore, the critical moisture content (CM) of the sample is that MC at which constant rate period terminates and the falling rate period commences. During this period, amount of internal moisture in the sample is reduced due to limiting amount of free unbound moisture in the sample. Hence, the sample surface does not have enough water, the little on the surface is rapidly driven away as the drying time is extended. These observations are in accordance with drying rate pattern for all agricultural and bio material such as food material (Antia *et al.,* 2019a and 2019b).

3.2 Total Colour Change of Dried Samples

The varaition of total colour changes observed in the dried plantian slices using various drying modes against drying time is shown in Figure 3.

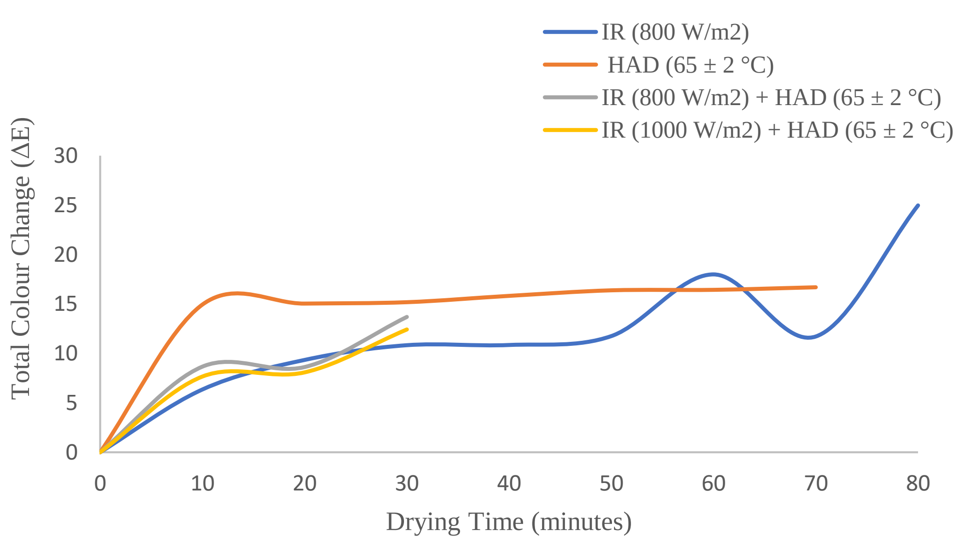

Figure 3: Variation of total colour changes observed in the dried plantian slices using various drying modes against drying time

The effectiveness of the various IR and HAD combination strategies (modes) could also be assessed by the changes in the colour of dried plantain samples. Hence, this could be used to select suitable drying techniques (Wang *et al.,* 2014a). From Figure 3, the total colour change (ΔE) of sample dried using IR-800 W/m^2 mode alone recorded at 10, 60 and 80 mins of drying time were 6.35, 17.99 and 24.97 (as the highest), respectively. The plantain samples dried at 10, 60 and 70 using HAD (65 ± 2 °C) mode alone had ΔE of 14.94, 16.43 and 16.93, respectively, whereas those samples dried at 10 and 30 min using IR (800 W/m^2) plus HAD (65 ± 2 °C) and IR (1000 W/m^2) plus HAD (65 ± 2 °C) modes gave ΔE of 8.66 and 13.69; and 7.66 and 12.42, respectively. As observed, ΔE in all the dried plantain slices samples using different combination strategies of IR and HAD, the use of IR (1000 W/m^2) plus HAD (HAD (65 ± 2 °C) gradually increased as the drying time also increased. However, sample dried using IR heating (800 W/m^2) alone had the highest ΔE (24.97) while IR (1000 W/m^2) plus HAD (65 ± 2 °C) had the least ΔE (12.42). Besides, the multiple comparison of the ΔE of the dried plantain samples using four modes is given in Table 1 using Tukey Honest Significant Difference.

Table 1: Mean ΔE Read between 10 to 30 Minutes for all the Drying Modes

Drying Mode	Mean ΔE
IR (800 W/m^2)	8.84 ± 2.28^a
HAD (65 ± 2 °C)	15.05 ± 0.12^b
IR (800 W/m^2) + HAD (65 ± 2 °C)	10.32 ± 2.91^a
IR (1000 W/m^2) + HAD (65 ± 2 °C)	9.38 ± 2.63^a

Note: M ± SD refers to mean and standard deviation; Values with the same superscript show no statistical significant difference at 5% level probability.

As observed in Table 1, plantain samples dried using HAD (65 ± 2 °C) mode recorded statistical significant mean difference in ΔE (15.05 ± 0.12) when compared with the other modes [with 8.84 ± 2.28, 10.32 ± 2.91, and 9.38 ± 2.63 for IR (800 W/m^2) alone, IR (800 W/m^2) plus HAD (65 ± 2 °C) and IR (1000 W/m^2) plus HAD (65 ± 2 °C), respectively] which did not show any significant mean difference at 5% level probability. For the purpose of comparison, 10 to 30 minutes drying time interval was chosen based on the fact that IR (1000 W/m^2) plus HAD (65 ± 2 °C) and IR (800 W/m^2) plus HAD (65 ± 2 °C) used 30 minutes to completely dried the products.

4. Conclusion

In this study, a combined hot air and infrared dryer was used to dry plantain slices at infrared intensities of 800 and 1000 W/m^2, and hot air drying (HAD-65 ± 2 °C) combination modes. Total colour of the dried samples for between 10 -30 mins were later evaluated. The results showed that the initial moisture content of fresh plantain slices determined by oven drying method was 55.84%w while those dried using IR-800 W/m^2 alone, HAD (65 ± 2 °C) alone, IR-800 W/m^2 plus HAD (65 ± 2 °C) and IR-1000 W/m^2 plus HAD (65 ± 2 °C) modes were 57.43, 52.13, 57.41 and 57.03% wb, respectively, whereas their corresponding critical or equilibrium moisture content were 5.62, 5.03, 12.45 and 5.95%wb, respectively. Shortest drying time (30 mins) and minimal total colour changes (ΔE = 12.42) were observed when IR (1000 W/m^2) plus HAD (65 ± 2 °C) was turned on. Statistically, plantain slices dried using HAD (65 ± 2 °C) mode between 10 - 30 mins showed significant mean difference in ΔE when compared with other three drying modes. Since, IR (1000 W/m^2) plus HAD (65 ± 2 °C) mode used the shortest drying time and minimal ΔE, it is recommended for use by restaurant /hotel operators and food processors in drying plantain slices.

References

Andrés, A., Fito, P., Heredia, A, and Rosa, EM. 2007. Combined drying technologies for development of high-quality shelf-stable mango products. Drying Technology, 25(11): 1857–1866.

Antia, OO., Assian, UE. and William, O. 2019a. Development of an empirical model relating palm nut moisture content, shell thickness and soaking time. *International* Journal of Mechanical and Civil Engineering, 2 (1): 36 - 47.

Antia, OO., Assian, UE. and William, O. 2019b. Effect of moisture content on palm nut shell fragmentation for effective separation of kernel. International Journal of Mechanical and Civil Engineering, 2 (1): 48-55

ASAE 2005. ASAE Moisture Measurement — Unground Grain and Seeds. American Society of Agricultural and Biological Engineers, pp. 2-4.

Farlex, F. 2011. Definition of drying; Free Online Dictionary, Thesaurus and Encyclopedia, https://www.thefreedictionary.com/drying accessed on 7th October, 2022

Kathiravan, K., Harpreet, KK., Jun, S., Joseph, I. and Ali, D. 2008. Infrared Heating in Food Processing: A Review. Comprehensive Reviews in Food Science and Food Safety, 7(1): 599–618.

Md- Fahim, HK. 2019. Study of Solar Radiation Measuring Instruments and Practical Measurement of Solar Radiation in Dhaka, Bangladesh. Islamic University of Technology, Dhaka, Bangladesh, 44p.

Moses, JA., Norton, T., Alagusundaram, K. and Tiwari, BK. 2014. Novel Drying Techniques for the Food Industry. Food Engineering Reviews, 6(3): 43–55.

Onwude, DI., Hashim, N. and Chen, G. 2016. Recent advances of novel thermal combined hot air drying of agricultural crops. Trends in Food Science and Technology, 57: 132-145., http://doi.org/10.1016/j.tifs.2016.09.012. accessed on 8th October 2022

Perera, CO. and Rahman, MS. 1997. Heat pump dehumidifier drying of food. Trends in Food Science and Technology, 8(3): 75–79.

Sandu, C. 1986. Infrared radiation drying in food engineering: A process analysis. Biotechnology Progress, *2*: 109–119.

Vernier Science Education (2020). Colorimeter User Manual https://www.vernier.com/manuals/col-bta/ accessed on 8th October 2022

Vishwanathan, KH., Hebbar, HU. and Raghavarao, KSM. 2010. Hot Air Assisted Infrared Drying of Vegetables and Its Quality. Food Science and Technology Research, 16(5):

381–388.
Zhang, M., Chen, H., Mujumdar, AS., Tang, J., Miao, S. and Wang, Y. 2017. Recent developments in high-quality drying of vegetables, fruits and aquatic products. Critical Reviews in Food Science and Nutrition, 57(6):1239–1255.