Journal of Animal & Plant Sciences, 2012. Vol. 13, Issue 2: 1771-1780
Publication date: 30/3/2012, http://www.m.elewa.org/JAPS; ***ISSN 2071 - 7024***

Effect of pretreatment and temperature on the air drying of French and False horn plantain slices

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Keywords: activation energy, plantain, moisture diffusivity, drying

1 SUMMARY

The objective of this study was to investigate the effects of pretreatment and drying conditions on plantain varieties, namely French horn and False horn, in a hot air drier at temperature range of 50°C to 80°C. Sliced samples from each variety were thoroughly mixed and divided into four groups of which one portion was dipped in citric acid, another in sodium Metabisulphite all for one minute and a third was steam blanched for 10 minutes. The fourth portion was not pretreated and it served as the control. Drying took place entirely in the falling rate period. Effective moisture diffusivity increased with increased drying air temperature and varied significantly ($p < 0.05$) with pretreatment. Temperature dependency of moisture on diffusivity was illustrated by the Arrhenius relationship. Over the range of temperature, effective moisture diffusivity varied from 7.54×10^{-10} to 2.37×10^{-9} and 5.17×10^{-10} to 3.11×10^{-9} for French horn and False horn respectively. Activation energy for drying ranged from 11.88 to 33.10 and 26.76 to 44.50 kJ/mol for French and False Horn respectively. The Effect of variety and pretreatment were significant ($p < 0.05$) on activation energy. The results suggest that citric acid and sodium metabisulphite pretreatment had a significant impact on the drying and were effective as temperature decreased.

2 INTRODUCTION

Plantain (Musa AAB) is a major source of carbohydrate in diets of people from Latin America, Africa and from South-east Asia (Marriott and Lancaster, 1983). It is estimated that 60 million people in West Africa derive more than 25% of their carbohydrate intake from plantain (Ortiz and Vuylsteke, 1996). They are consumed both as energy-yielding food and as dessert, providing more than 200 calories (food energy) a day (Stover and Simmonds, 1987). Plantains are known to be a great source of calcium, vitamins A, B_1, B_2, B_3, B_6, C and minerals such as potassium and phosphorous. In Ghana, plantains contribute about 13.1% of the Agricultural Gross Domestic Product (AGDP) and its per capita annual consumption of 96.4 kg (Lescot, 2000) is higher than other starchy staples except cassava. It is of great socio-economic and nutritional significance and generates considerable employment. Annual production in the country is about 1.8 metric tons for AAB subgroup of which only 0.5 tons is exported (Lescot, 1999). Several varieties of plantain are cultivated in West Africa. These are classified as French Horn Plantain, False Horn Plantain or the True Horn Plantain (Ahiekpor, 1996, Hemeng *et al.*, 1996). These varieties have different morphological traits and physiochemical characteristics and are therefore utilized in various ways like baking, roasting, frying and boiling, pounding as in the case of "fufu" (Danso *et al*., 2006). Ogazi (1982) reported that over 80% of the crop is harvested during the period of September to February, and that there is much wastage during this period as some of the products do not store for a long period. This results in seasonal unavailability and limitations on the use by urban population. Therefore, there is a need to develop preservation methods for this crop.

Air-drying is considered to be one of the simplest and most economical ways of commercially processing fruit and vegetables (Brennan *et al.,* 1990). Air-drying could be considered as appropriate to developing countries as the product, suitably packaged, can be stored for several months without the risk of spoilage and can be milled into flour and rehydrated for a variety of uses (Marriott and Lancaster, 1983). The pulp of the plantain species used is usually orange or yellow, but the colour of the processed flour is dark brown (Ngalani, 1989). The discoloration phenomenon has been attributed to enzymatic browning, due to the action of polyphenol oxidase (Almentros and Del Rosatio, 1985) and the production of polyphenols and derived products (Osagie and Opoku, 1984).

Some pretreatments employed to abate these problems include sulphiting (soaking in sulphite solutions) and blanching (soaking in hot water). These pretreatments affect the drying characteristics and energy requirements during drying of plantain slices by resulting in a coating which apparently breaks down the pulp surface, resulting in a reduced resistance to moisture loss. Although, considerable amount of food materials are dried artificially in heated mechanical air-drying systems (Das et al., 2001; Doymaz, 2004a, 2004b; Senadeera, et al, 2003), there is little or no information on the influence of the pretreatments on the energy requirements during the drying of plantains. Thus the objectives of this work is to investigate the effects of variety and processing conditions on (1)the drying characteristics, and (2) activation energy for drying of French Horn and False Horn.

3 MATERIALS AND METHODS

3.1 Material: False horn and French horn plantain produced by Crop Research Institute of the centre for scientific and industrial research, in Fumesua Town was used in the study. False Horn and French Horn had an initial moisture content of 61.1 ± 1.2 %and 62.5 ± 2.5% (wet basis) respectively as determined by drying in an oven (Genlaboven model D35, MIDO/3/SSF, England) to a constant weight.

3.2 Sample preparation: Finger samples were collected from the second hand of the proximal end of the bunch following the recommendation of Baiyeri and Ortiz (2000) the same day the bunch was harvested. Samples were immersed in a plastic bowl with potable water and then peeled with the aid of a stainless kitchen knife. The pulp was then sliced into cylindrical discs with same thickness of 10mm sliced samples from each variety were thoroughly mixed and divided into four groups. One portion was dipped in citric acid (CIT) (1% w/w) for one minute. Another was dipped in sodium Metabisulphite (MBS) (21g/l) for one minute. A third portion was steam blanched (BLA) for 10 minutes. The fourth portion was not pretreated and it served as the control (CON). Accumulation of moisture on the sliced surface as a result of the pretreatment was drained with a cheese cloth before samples were transferred to the dryer.

3.3 Drying equipment and process: An experimental Gas dryer was used in the study. This consist of a wooden chamber on wooden stand, a compartment at the base for housing the gas burner, and a single door serving as the main opening. The drying compartment had ten moveable trays with wire mesh base. The walls of the chamber were double layered and have an air gap of 0.02m thick. The fifth tray was used in the study. Sliced samples all of equal thickness of 10mm and diameter 30mm were loaded in the gas dryer on trays with a wire mesh base (0.2m x 0.2m; an average of 30 discs) in a single layer. Drying experiments were conducted at 50, 60, 70 and 80°C (±1°C). The dryer was allowed to run for 30 min to reach the set drying air temperature conditions. The rate of drying and the drying profile of the various plantain cultivars were determined by evaluating the moisture content of the samples taken at a constant interval of 30 minutes by a digital balance (Triton 201, USA) of 0.01 g accuracy. Drying curves of moisture ratio versus drying period were determined to depict drying profile graphically.

3.4 Mathematical modeling: For a slab, the solution of Fick's second law, with the assumption of moisture migration being by diffusion, negligible shrinkage, constant temperature and diffusion coefficients and long drying times is given below.

$$MR = \frac{M_t - M_c}{M_o - M_c} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left[\frac{-(2n+1)^2\pi^2 D_{eff}\, t}{4L^2}\right] \quad (1)$$

Where D_{eff} is the effective moisture diffusivity (m^2s^{-1}), L is the half thickness which in this case is 5mm and t is the drying time.

Equation (1) can also be written in a simplified form as

$$MR = \frac{M_t - M_c}{M_o - M_c} = a\exp(-k\,t) \quad (2)$$

Equation (2) is known to be the exponential equation. An alternative approach to analysis of thin layer drying has been to use empirical relationships. One equation that has been widely used in thin layer drying studies is Page's equation (Equation 3) (Diamante and Munro, 1993)

$$MR = \frac{M_t - M_c}{M_o - M_c} = a\exp(-k\,t^y) \quad (3)$$

In these models MR is the dimensionless moisture ratio = $(M_t - M_c)/(M_o - M_c)$, where M_t is the moisture content of the product at each moment, M_o is the initial moisture content of the product and M_c is the equilibrium moisture content. The values of M_c are relatively small compared to M_t and M_o. Thus MR= $(M_t - M_c)/(M_o - M_c)$ was reduced to MR= M_t/M_o (Doymaz, 2004a; Doymaz and Pala, 2002; Lomauro et al. 1985).

Several researchers have demonstrated that equation (1) could further be simplified to a straight line (equation 4) (Dadali, et al., 2007b).

$$\ln MR = \ln\left[\frac{8}{\pi^2}\right] - \left[\frac{\pi^2 D_{eff}\ t}{4L^2}\right] \quad (4)$$

The effective moisture diffusivities were calculated by plotting experimental drying data in terms of ln(MR) versus time (equation 4) and the plot gives a straight line with a slope of

$$Slope = \frac{\pi^2 D_{eff}}{4L^2} \quad (5)$$

Karatas (1997) and Senadeera *et al.* (2003) reported the correlation between the drying conditions and the values of the effective diffusivity using Arrhenius type equation:

$$D_{eff} - D_0 \exp[E_a/RT] \quad 6$$

where D_o = diffusion coefficient; E_a = activation energy (kJ/mol); R = universal gas constant (8.314 J/mol K); T = absolute air temperature (K).

3.5 Statistical analysis: Results were evaluated for analysis of variance (ANOVA) using STATGRAPHICS CENTURION XV

4 RESULTS AND DISCUSSION

4.1 Effects of pretreatment and variety on moisture ratio and drying rate of plantains: The moisture contents and moisture ratio of plantain slices decreased with drying time. Moisture ratio of blanched (BLA) French horn and False horn were higher than fresh untreated (CON), sulphited (MBS) and citric acid (CIT) treated samples. Figures 1 and 2 show the effect of pretreatment on moisture ratio of French horn and false horn air-dried at 70 °C.

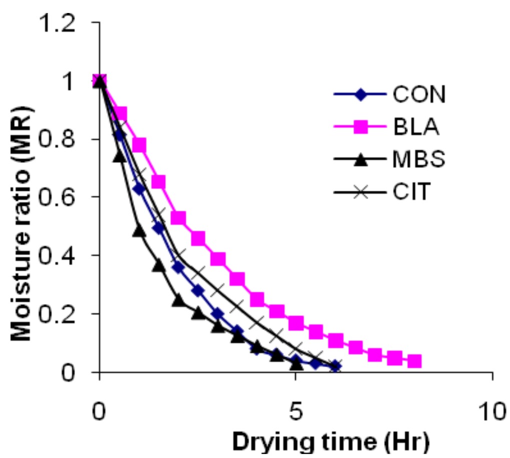

Figure1: Effect of temperature on moisture ratio of False horn during drying at 70°C

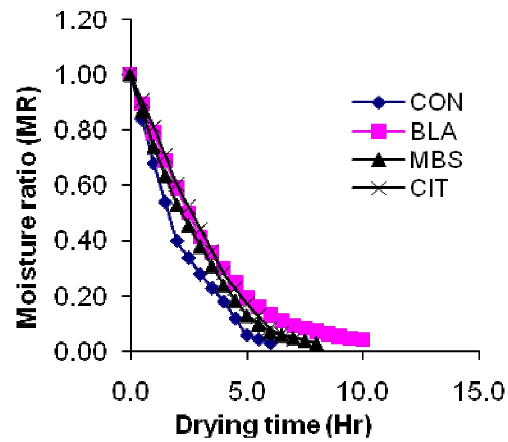

Figure2: Effect of temperature on moisture ratio of French horn during drying at 70°C.

Blanching may have caused the gelatinization of plantain starches, resulting in a decreased rate of moisture movement from within the material to the surface during air-drying. Similar result was reported during air-drying of blanched banana by Dandamrongrak et al., (2003). Typical drying rate curves for French horn and false horn showing the effect of pretreatment are illustrated in Fig. 3 and 4 respectively.

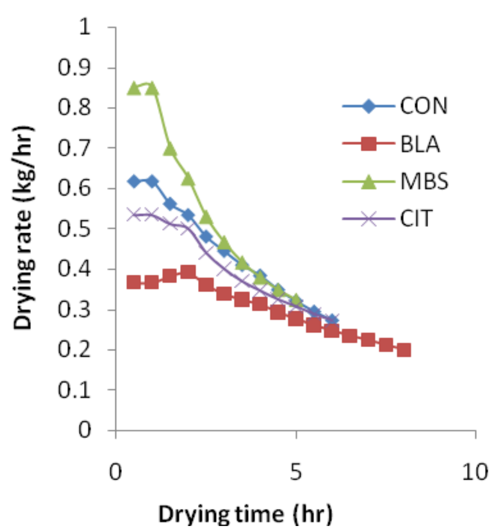

Figure 3: Drying rate curve of French horn during drying at 70°C

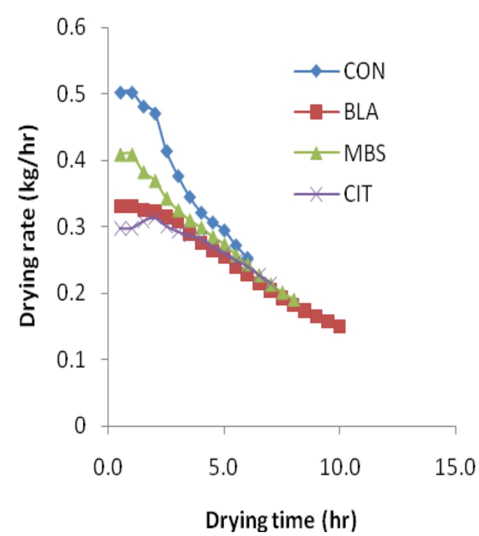

Figure 4: Drying rate curve of false horn during drying at 70°C

Generally, drying rates decreased with decreased moisture contents, and drying occurred in the falling rate period. This refers to the period when the material that is being dried heats up, causing water to move from the interior to the surface for evaporation. Drying rates were initially high during the first and second hours of drying (Fig. 3and4) when moisture contents were high, after which the drying rate decreased steadily with decreased moisture contents. This trend could be due to the removal of free moisture near the surface of the plantain slices at the early stages of drying. Blanched

4.2 Effect of temperature on moisture ratio and drying rates of plantain slices: Moisture ratio decreased with increasing drying temperature. Figure 5 shows the effect of temperature on moisture ratio of citric acid treated slices during air-drying of False Horn. A similar trend was observed for French Horn in all treatment variations. Generally, higher drying temperatures resulted in shorter drying times and steeper drying curves. The time required to reduce the moisture ratio to any given level was dependent on the drying temperature. According to Doymaz (2005), the

plantain slices showed lower drying rates compared to the other treatments. Results are in agreement with observations in the drying of prickly pear fruit (Lahsasni et al, 2004), potato (Srikiatden and Roberts, 2003) and banana (Dandamrongrak *et al*., 2003). Alzamora and Chirife, (1980) reported that blanching of potato did not increase the rate of drying because of starch gelatinization that resulted in reduced porosity (Mate et al, 1998). Dandamrongrak *et al.* (2003) also reported that blanching did not result in reduced drying time in banana due to the effect of starch gelatinization. effect of drying air temperature was most dramatic with moisture ratio as moisture ratio decreased rapidly with increased drying air temperature. There was generally a short constant rate at the start of the drying but the drying occurred predominantly in the falling rate period. This showed that diffusion is the dominant physical mechanism governing moisture movements in the plantain samples. Similar results were reported for green bean (Roselloet al, 1997), okra (Doymaz, 2004b; Gogus and Maskan, 1999), red chilli (Guptaet al, 2002) and eggplant (Ertekin and Yaldiz, 2004).

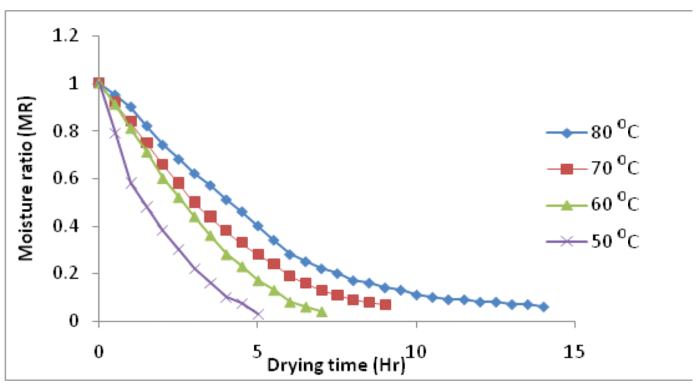

Figure 5: Effect of temperature on moisture ratio

4.3 Effect of pretreatment on effective moisture diffusivity of plantain slices: The mechanism of moisture movement within a hygroscopic solid during the falling rate period can be represented by effective moisture diffusion phenomena which include liquid diffusion, vapour diffusion and other possible mass transfer mechanisms. Effective moisture diffusivity is used to represent an overall mass transport property of water in food materials (Dadali *et al*.,2007)A graph of lnMR (moisture ratio) against time was plotted, as extrapolated from equation 4. From its slope (Equation 5) effective moisture diffusivity (D_{eff}) was estimated. Calculated moisture diffusivities of French and False horn varied with pretreatment (Table 1). Generally, effective moisture diffusivity increased with increased drying air temperature. Blanched French Horn showed lower D_{eff} values followed by CIT, CON and MBS in ascending order (Table 2). D_{eff} values of False Horn was in the order CON> MBS> CIT> BLA.

Table 1: Values of effective diffusion coefficient obtained at various temperatures and treatments for French Horn, False Horn and FHIA-21

Pretreatment	Temperature of drying air (°C)	Effective diffusion coefficient (m^2/s)	
		French horn	False horn
CON	80	2.37×10^{-09}	3.11×10^{-09}
CON	70	1.88×10^{-09}	1.60×10^{-09}
CON	60	1.35×10^{-09}	1.36×10^{-09}
CON	50	8.10×10^{-10}	6.64×10^{-10}
BLA	80	1.39×10^{-09}	1.29×10^{-09}
BLA	70	1.15×10^{-09}	$9.62 \times 10\text{-}^{10}$
BLA	60	9.59×10^{-10}	8.44×10^{-10}
BLA	50	7.54×10^{-10}	5.17×10^{-10}
MBS	80	2.31×10^{-09}	2.49×10^{-09}
MBS	70	1.63×10^{-09}	1.28×10^{-09}
MBS	60	1.80×10^{-09}	9.87×10^{-10}
MBS	50	1.34×10^{-09}	7.00×10^{-10}
CIT	80	1.85×10^{-09}	1.82×10^{-09}
CIT	70	1.81×10^{-09}	1.27×10^{-09}
CIT	60	1.42×10^{-09}	8.72×10^{-10}
CIT	50	1.31×10^{-09}	6.96×10^{-10}

Comparably low moisture diffusivity values of blanched French and False Horn could be due to resistance to moisture migration as a result of gelatinization of starch granules. Dandamrongrak *et al.* (2003) and Njitang and Mbbofung (2003) reported similar results for drying of banana and taro respectively. This result is in agreement with previous studies by Senadeera *et al.* (2003) on potato. The results indicated that diffusion is the most likely physical mechanism governing moisture movement in French and False horn. Drying during falling rate period is governed by water diffusion in the solid. This complex mechanism involving water in both liquid and vapour states is often characterized by effective moisture diffusivity (Al Hodali, 1997). Effective moisture diffusivity varied from 7.54×10^{-10} to 2.37×10^{-9} and 5.17×10^{-10} to 3.11×10^{-9} for French horn and False horn respectively. These values lie within the general range of 10^{-11} to 10^{-6} m2/s reported by Zogzas et al, (1996) and Marinos-Kouris and Maroulis (1995) for food materials. Srikiatden and Roberts (2003) also reported the moisture diffusivity range for potato, carrot core, carrot cortex and apple as 4.68×10^{-10} to1.02×10^{-9}.

4.4 Activation energy for drying of plantain slices: The natural logarithm of calculated moisture diffusivities ($\ln D_{eff}$) were plotted against the reciprocal of the absolute temperature (1/Tabs). Activation energy (kJ/mol) which is the minimum amount of energy required for the onset of the drying process was calculated from the slope with high correlation coefficients ($R^2 = 0.874$–0.998 for French Horn; $R^2 = 0.946$– 0.955 for False horn), indicating a good fit. Activation energy for drying is the energy required to initiate mass diffusion from a wet food material during drying (Mittal, 1999). Activation energy for drying ranged from 11.88 to 33.10 and 26.76 to 44.50 kJ/mol for French and False Horn respectively, depending on pretreatment and thickness of plantain slices (Table 2). The energy of activation(Ea) obtained in our work (Table 3) are comparable with existing literatures by Sabarez and Price (1999) for prune (57.00 kJ/mol), Doymaz (2004a) for carrot (28.39 kJ/mol), Doymaz (2005) for okra (51.26 kJ/mol), Bon, Simal, Rosello, and Mullet (1997) for potato (20.0 kJ/mol) and Park, Vohnkova, and Brod (2002) for mint (57.0 kJ/mol).

Table 2: ACTIVATION ENERGY (KJ/mol)

Variety	CON	BLA	MBS	CIT
French horn	33.10	18.73	15.29	11.88
False horn	44.50	26.76	37.54	28.99

Values of the energy of activation lie within the general range of 12.7–110 kJ/mol for food materials (Zogzas *et al.,* 1996) except for citric acid pretreatment of French Horn. This anomaly could be due to the high drying rate of CIT pretreated for French horn as temperature decreased compared with the other pretreatments (Table 3). Effect of variety and pretreatment were significant ($p < 0.05$) on activation energy.

Table 3: Effect of pretreatment and temperature on average drying rate (kg water/hr) of French Horn and False Horn

VARIETY	temperature / pretreatment	80°C	70°C	60°C	50°C
FRENCH HORN	CON	0.65(0.17)^{b}	0.43(0.12)^{b}	0.33(0.09)^{b}	0.20(0.03)^{a}
	BLA	0.34(0.08)^{a}	0.29(0.06)^{a}	0.23(0.06)^{a}	0.16(0.19)^{a}
	MBS	0.68(0.27)^{b}	0.55(0.19)^{c}	0.42(0.10)^{c}	0.27(0.21)^{a}
	CIT	0.43(0.14)^{c}	0.40(0.09)^{b}	0.38(0.17)^{c}	0.30(0.30)^{b}
FALSE HORN	CON	0.75(0.15)^{d}	0.37(0.09)^{c}	0.29(0.06)^{b}	0.15(0.02)^{ab}
	BLA	0.31(0.05)^{a}	0.24(0.06)^{a}	0.21(0.05)^{a}	0.13(0.04)^{a}
	MBS	0.58(0.16)^{c}	0.29(0.07)^{a}	0.19(0.04)^{a}	0.17(0.03)^{c}
	CIT	0.46(0.12)^{b}	0.28(0.03)^{ab}	0.22(0.03)^{a}	0.16(0.03)^{c}

CON: Control; BLA: Blanched; MBS: Sodium Meta bisulfate; CIT: Citric acid. Means with the same letter for a column of a particular variety are not significantly different at 5%. Values in bracket are standard deviations.

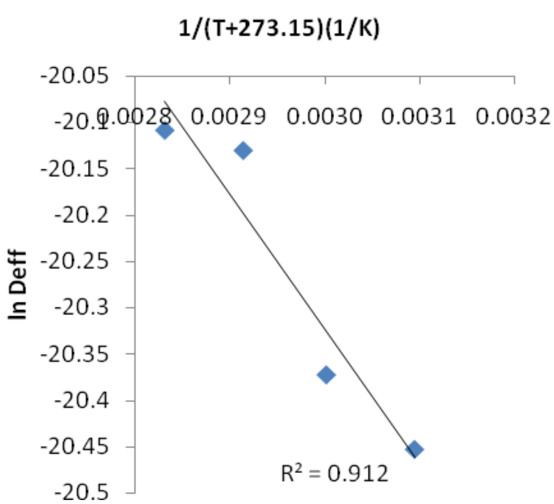

Figure 6: In D_{eff} against 1/T of French horn for CIT pretreatment

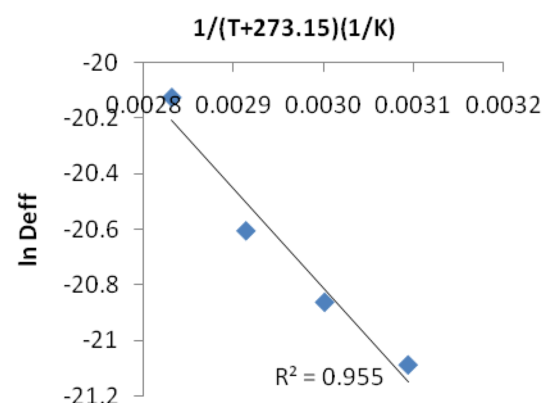

Figure 7: In D_{eff} against 1/T of False horn for CIT pretreatment

5 CONCLUSION

The effect of blanching, sodium meta bisphite and citric acid on hot air drying of French and False horn was studied. Drying of untreated, blanched, citric acid and sulphited French and False horn took place entirely in the falling rate period. Moisture ratio and drying rate decreased with increased drying air temperature. Generally, blanched plantain showed lower moisture ratio, drying rate and Deff than sulphited citric acid and untreated plantain slices. Activation energy for drying were significantly ($p < 0.05$) affected by pretreatment of plantain. Moreover, activation energy for drying of False horn (26.76–45.50 kJ/mol) was significantly higher than French horn (11.88–33.10 kJ/mol).

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