Effect of enzymatic pretreatment on the physical quality of plantain (*Musa* ssp., group AAB) employing airflow reversal drying

J. Rodríguez-Miranda¹ · C. E. Martínez-Sánchez¹ · B. Hernández-Santos¹ ·
J. M. Juárez-Barrientos¹ · E. G. Ventura-Báez¹ · E. Herman-Lara¹

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Abstract This work aimed to evaluate the effect of enzymatic pretreatment on the color and texture of plantain (*Musa* ssp., group AAB) dried by airflow reversal drying. Plantain slices 1.0 cm thick were used. Pretreatment with two commercial enzymes, Pectinex Ultra SPL (*Aspergillus aculeatus*) and Pectinex 3XL (*Aspergillus niger*), was performed. Drying kinetics were determined with and without pretreatment at temperatures of 50, 65 and 80 °C using a fixed bed convective dryer. An air speed of 6 m/s, a bed height of 5 cm and either unidirectional flow or airflow reversal (every 15 min) were used for drying. Color and texture were analyzed, and consumer acceptance of the results of the best treatments was determined. Pretreatment with the enzyme *A. niger* and airflow reversal gave the best drying kinetics and showed the greatest reduction in drying time (59.0%) at 80 °C. The best hardness results were found at 80 °C with *A. niger* enzymatic pretreatment with both types of air flow. Brightness and hue angle showed that samples pretreated with enzymes and dried at 65 °C had a lighter yellow color compared to non-pretreated samples. Plantain samples enzymatically pretreated and dried at 65 and 80 °C were the most accepted by consumers. This kind of enzymatic pretreatment on plantain could allow the conservation of some physical properties and reduction of drying times relative to the current methodology.

Keywords *Aspergillus aculeatus* · *Aspergillus niger* · Color · Texture · *Musa* ssp.

Introduction

Drying is a complex process involving the simultaneous transfer of matter and energy. Fruits and vegetables have certain morphological characteristics clearly distinct from other natural materials that greatly influence their behavior during drying and storage (Tunde-Akintunde 2014). Fruits are characterized by high initial moisture content, high temperature sensitivity (i.e., color, flavor, texture and nutritional value are subject to thermal deterioration), and drying shrinkage (Krokida et al. 2003). The amount of thermal energy required for drying a particular product depends on many factors, such as the initial moisture content, desired final moisture content, temperature, relative humidity of the drying air and air flow rate (Karim and Hawlader 2005; Di Scala et al. 2011). Traditional drying on a fixed-bed with airflow in one direction causes increased shrinkage and cracking of the product during the process, resulting in increased time and cost associated with drying the product (Ruiz-López and García-Alvarado 2007). An economical way to avoid excessive moisture content and temperature gradients in the product to be dried is to change or reverse the direction of airflow periodically during drying, keeping in mind the bed depth, particle thickness, air speed and drying air temperature (Herman-Lara et al. 2010). Previous studies have employed pectinolytic and cellulolytic enzymes as pretreatments in foods with strong textures to soften them and thereby increase digestibility, increase the penetration of heat inside plant tissues facilitate water removal, improve product quality and increase the efficiency of the process (Lisińska et al.

✉ E. Herman-Lara
erasmo_hl@hotmail.com; erasmohl@ittux.edu.mx

¹ Departamento de Ingeniería Química y Bioquímica,
Coordinación de Posgrado e Investigación, Tecnológico
Nacional de México/Instituto Tecnológico de Tuxtepec, Av.
Dr. Víctor Bravo Ahuja S/N, Col. 5 de Mayo, Tuxtepec,
68350 Oaxaca, Mexico

2007). However, in the literature, there are no published studies about the effect of enzymatic pretreatments on the physical characteristics of drying in some fruits, including plantains (*Musa* ssp., group AAB). This fruit is one of the most important carbohydrate sources for people living in humid regions of Latin America, Africa and South Asia (Tunde-Akintunde 2014). Plantain fruit is highly perishable. Mishandling of materials postharvest, high temperatures and humid conditions that prevail in the tropics, postharvest losses due to the high rate of metabolism of bananas, and storage of plantain-derived products for only a few days, are factors that limit the use of plantains in both commercial and non-commercial applications (Falade et al. 2003). Therefore, the aim of this study was to evaluate the effect of enzymatic pretreatment with two commercial enzymes, Pectinex® Ultra SPL (*Aspergillus aculeatus*) and Pectinex® 3XL (*Aspergillus niger*), on the color and texture of plantains using airflow reversal during drying.

Materials and methods

Raw material

Plantains were acquired at a local market in the city of Tuxtepec, Oaxaca, Mexico. The fruit used was in stage four of maturation according to Escalante-Minakata et al. (2013). Plantains were washed, and then, the peel and ends were removed. The center of the fruit was cut into slices 1.0 cm thick and 3.0 cm in diameter.

Enzymatic pretreatment

Two commercial enzymes, Pectinex® 3XL (P2736; Sigma-Aldrich Co. St. Louis, USA) and Pectinex® Ultra SPL (P2611; Sigma-Aldrich Co. St. Louis, USA), from the microbial strains of *A. niger* and *A. aculeatus*, respectively, were used in pretreatments. Plantain slices were immersed in an enzyme solution of 0.06 mL enzyme/100 mL of distilled H₂O (v/v) at 40 °C for 30 min. Enzyme concentration, temperature and time in the solution were determined from preliminary tests based on the primary activation temperatures of the enzymes (according to data provided by the chemical supplier). Slices were subsequently subjected to convective drying on a fixed bed.

Experimental drying kinetics

A fixed bed dryer using hot air flow in one direction (U) and airflow reversal every 15 min (R) was used for drying plantain slices (Herman-Lara et al. 2010). The drying air velocity was constant at 6 m/s, and the drying was performed in multiple layers of plantain slices until reaching a

fixed bed height of 5.0 cm in the dryer chamber. Weight loss of the samples was recorded at regular time intervals until a constant weight was reached. A constant weight was assumed to be a mass variation of less than 0.05 g in each drying batch using a digital balance with an accuracy of 0.001 g (Sartorius TE 4101 AG Göttingen, Germany, 2010). The dried samples were packaged in bags using a vacuum sealant (Food Saver Oster Vacuum Packing System V2040IN, 1 Francis Grove, London SW19 4DT, UK) for further analysis. A dimensionless moisture content (Ψ) was calculated using Eq. 1. The experimental drying kinetics were graphed with drying time in minutes versus Ψ . Thus, all graphs started from the same initial moisture content for each drying kinetics experiment because the initial moisture contents of the plantains used in each experimental run were different. The initial moisture content was obtained by the oven method (AOAC 2005).

$$\Psi = \frac{X - X_e}{X_0 - X_e} \quad (1)$$

where Ψ represents a dimensionless moisture content, X represents the moisture content of plantain at time “t” (g H₂O/g dry matter), X_e represents the equilibrium moisture content (g H₂O/g dry matter) and X_0 represents the initial moisture content (g H₂O/g dry matter).

Texture determination

A Brookfield texturometer (CNS QTS25 Farnell/Brookfield, Brookfield Viscometers, England, UK) was used to evaluate the fracture hardness of plantain slices. Hardness testing was performed with a cylinder 6 mm in diameter and a constant speed of 1 mm/s (Ikoko and Kuri 2007). The maximum fracture strength was determined at a constant speed of 30 mm/min. Ten repetitions per sample were carried out. The values are reported in Newtons (N).

Color determination

A MiniScan XE Plus colorimeter (A60-1010-352, Hunter Associates Laboratory 11491 Sunset Hills Road Reston, Virginia 20190, USA) was used to determine color parameters of brightness (L^*), a^* , b^* and hue angle (h°). The results were expressed according to the CIELAB system with reference to illuminant D65 and a visual angle of 10°.

Sensory evaluation

A test of sensory evaluation by consumers was developed with 100 untrained panelists. The plantain samples were coded, and consumers were asked to taste samples and score them in terms of overall acceptability using a nine-

point hedonic scale (1 = I dislike very much, 9 = I like very much).

Experimental design and statistical analysis

A completely randomized statistical design with a factorial arrangement was used to analyze the following three variables: (a) airflow type with two levels [unidirectional (U) and reversed every 15 min (R)], (b) enzymatic pretreatment with three levels (without pretreatment, *A. niger* and *A. aculeatus*) and (c) temperature with three levels (50, 65 and 80 °C). The results of texture analysis, evaluation of color parameters and sensorial acceptance levels were evaluated with analysis of variance (ANOVA), and the differences between the means were calculated using a least significant difference (LSD) test with a confidence level of 95%. All analyses were performed with Statistica software ver 8.0 (StatSoft, Inc. USA). All analyses were performed in triplicate except texture tests, in which ten replicates were performed.

Results and discussion

Experimental drying kinetics

The results of experimental drying kinetics of plantain at 50, 65 and 80 °C using the two drying airflows (U and R) without enzymatic pretreatment are shown in Fig. 1a. To see the effect of temperature and drying airflow most clearly, drying time analysis was used and referenced to a dimensionless moisture content of $\Psi = 0.2$. In the kinetics determinations where U and R flows were used, as expected, as the drying air temperature increased, the drying times were shorter (Falade and Ogunwolu 2014). The above behavior was due first to elimination of the free surface moisture, and the water inside the slices was removed through diffusion, in which liquid was transported to the surface pores by capillarity action promoted by the surface evaporation. Researchers such as Demirel and Turhan (2003) observed this effect during the dehydration of pretreated banana slices with sodium bisulfite and ascorbic acid/citric acid. As shown in Fig. 1a, to reach the same dimensionless moisture content of $\Psi = 0.2$ using U, the times required were 352.8, 268.8 and 205.4 min at 50, 65 and 80 °C, respectively. The drying time was reduced by 41.8% between the highest and lowest temperature when U air flow was used. To reach the same $\Psi = 0.2$ with R air flow at 50, 65 and 80 °C, the drying times were 21.6, 7.4 and 19.0 min less, respectively, than the times required to dry samples at the same temperatures using U air flow (Table 1). A maximum savings in drying time of 47.2% was obtained using R air flow and a temperature of 80 °C;

Fig. 1 Drying kinetics of plantain: **a** unpretreated plantain samples employing unidirectional airflow (U) and reversal airflow (R) at 50, 65 and 80 °C, **b** pretreated plantain samples with enzymes of *A. niger* and *A. aculeatus* employing U at 50, 65 and 80 °C, **c** pretreated plantain samples with enzymes of *A. niger* and *A. aculeatus* employing R at 50, 65 and 80 °C

the drying time was 166.3 min less than the time required at 50 °C with U air flow. However, the drying time was only 5.4% shorter between U and R air flows at the same temperature. This effect of reducing drying time by using R air flow was because moisture gradients within samples were distributed from the center to the bottom or top

Table 1 Percent of saving drying time with enzymatically pretreated and unpretreated samples employing unidirectional airflow (U) and reversal airflow (R) at temperatures of 50, 65 and 80 °C

Treatments	Saving time (min)	Saving time (%)	Required time (min) to reach ($\Psi = 0.2$)
50 °C unpretreated “U”	0	0	352.8
50 °C <i>A. niger</i> “U”	32.0	9.1	320.8
50 °C <i>A. aculeatus</i> “U”	21.0	6.0	331.8
50 °C unpretreated “R”	21.6	6.1	331.1
50 °C <i>A. niger</i> “R”	72.4	20.5	280.4
50 °C <i>A. aculeatus</i> “R”	65.3	18.5	287.5
65 °C unpretreated “U”	84.0	23.8	268.8
65 °C <i>A. niger</i> “U”	128.7	36.5	224.1
65 °C <i>A. aculeatus</i> “U”	112.8	32.0	240.0
65 °C unpretreated “R”	91.4	25.9	261.4
65 °C <i>A. niger</i> “R”	134.4	38.1	218.5
65 °C <i>A. aculeatus</i> “R”	116.6	33.1	236.2
80 °C unpretreated “U”	147.4	41.8	205.4
80 °C <i>A. niger</i> “U”	190.5	54.0	162.2
80 °C <i>A. aculeatus</i> “U”	181.6	51.5	171.1
80 °C Unpretreated “R”	166.4	47.2	186.4
80 °C <i>A. niger</i> “R”	208.1	59.0	144.7
80 °C <i>A. aculeatus</i> “R”	202.8	57.5	150.0

Referencing the temperature of 50 °C with unidirectional airflow (U) and unpretreated samples (352.76 min drying time)

surface, forming lower moisture gradients in the samples and thus in the drying bed, allowing water to more easily exit the interior of the plantain slices since the diffusion of the water is transferred to only half the length of the sample and the drying compared to the full sample and bed length when unidirectional air flow is used, where heat-sensitive materials will dry faster in the air inlet zone (Ratti and Mujumdar 1994). In contrast, Herman-Lara et al. (2010) simulated the drying of carrot slices using R air flow and reversing times of 15 and 30 min at 50 and 70 °C, and they observed a decrease in drying time. In addition, similar results were obtained by Sampaio et al. (2007) in their evaluation of the quality of coffee dried at 60 °C using airflow reversal. The results of drying kinetics with enzymatic pretreatments using U air flow from the present study are shown in Fig. 1b, and decreases in drying times are shown in Table 1. Considering a moisture content of $\Psi = 0.2$ at all temperatures, the drying times were shorter when using *A. niger* than when using *A. aculeatus*. With U air flow, plantain samples pretreated with *A. niger* had drying times of 11.0, 15.9 and 8.9 min less than when *A. aculeatus* was used at 50, 65 and 80 °C, respectively. The greatest decrease in drying time was 54.0% (190.5 min) when *A. niger* was used at 80 °C with U air flow (Table 1). The same behavior was observed when plantain samples were dried with R air flow and enzymatic pretreatments (Fig. 1c); drying times were shorter using *A. niger* than

when using *A. aculeatus* at all tested temperatures. Samples pretreated with *A. niger* had drying times that were 7.1, 17.8 and 5.3 min less than when *A. aculeatus* was used at 50, 65 and 80 °C, respectively. The drying time was shortened the most when *A. niger* was used at 80 °C (59.0%, 208.1 min; Table 1). Therefore, when pretreatments with *A. niger* and airflow reversal were used, shorter drying times and higher percentages of time saved were obtained compared to when samples were pretreated with *A. aculeatus* or samples were not pretreated at all temperatures tested in this study. In general, enzymatic pretreatment helped to reduce drying times compared to plantain samples that were not pretreated at the same temperatures; this could be due to enzymatic hydrolysis of cell wall polysaccharides (pectin, cellulose and hemicellulose) in the plantain samples. Their tissues are composed of parenchymatous cells with cell walls primarily composed of these types of polysaccharides (Buchert et al. 2005). The commercial enzymes (Pectinex® Ultra SPL and Pectinex® 3XL) in the applied pretreatments are a mixture of pectin transeliminase, polygalacturonase, pectinesterase, and small amounts of hemicellulase and cellulase enzymes that degrade the polysaccharides present in this type of plantain tissue, thus increasing the formation of new pores, the size of existing pores and the total porosity of the substrate (cell wall) and allowing greater water diffusion through the plantain tissue promoting the release of water

from the inside the tissue onto the surface. Lisińska et al. (2007) used scanning electron microscopy to analyze the changes in the structure of the cellular tissue of potatoes caused by enzymatic treatment. Due to the higher enzymatic activity of Pectinex® 3XL, it was decided to test only samples pretreated with *A. niger* against untreated samples with R air flow in the consumer preference tests.

Hardness

Hardness is a texture parameter considered predominantly a mechanical feature. This term is defined as the maximum force required to break the food product (Demattè et al. 2014). Figure 2 shows the effect of enzymatic pretreatment on the hardness of the plantain samples using U and R air flows at all tested temperatures. At 50, 65 and 80 °C, significant differences were found ($p < 0.05$) among samples without pretreatment using U and R air flows and the samples pretreated with either enzyme. Among the samples that had not been pretreated, there was no difference at the temperatures employed except at 65 °C. At 50 °C, no significant differences were found ($p > 0.05$) between the enzyme treatments, except for samples pretreated with *A. aculeatus* and dried with R air flow (99.2 N) in which the highest value of texture was obtained. At 65 °C, significant differences were observed ($p < 0.05$) among samples pretreated with *A. niger* and *A. aculeatus* in the two types of airflow used. In treatments with *A. niger*, lower hardness values were found. A hardness value of 82.2 N was obtained for the sample treated with *A. niger* using R air flow. However, between *A. niger* treatment with R air flow and *A. niger* treatment with U air flow, no significant

difference was found ($p > 0.05$). At 80 °C, a significant difference was observed between the samples pretreated with *A. niger* and *A. aculeatus* and dried with the two types of airflow. The samples treated with *A. niger* had lower hardness values. The samples treated with *A. niger* and dried with R air flow had a hardness value of 42.8 N; however, there was no significant difference ($p > 0.05$) between samples with this treatment and samples with pretreatment with *A. niger* and dried with U air flow. In the samples treated with *A. niger*, the final textures tended to decrease with increasing temperatures. This result was due to the effect of the enzymatic pretreatment, which caused hydrolysis of the polysaccharides of the cell walls, including pectins, celluloses and hemicelluloses, causing cellular degradation of the plantain tissue (Koley et al. 2011). The pectinolytic enzymes are currently used in industrial processing to facilitate the extraction of juice in some fruits by causing rupture of the cell wall, thus improving process yield (Buchert et al. 2005; Puupponen-Pimiä et al. 2008). The effects of various treatments on the texture of foods have been reported in studies carried out by Zhenfeng et al. (2007), where they studied the influence of storage temperature on the texture properties (elasticity, chewiness and hardness) of Chinese bayberry fruit. Zdunek and Bednarczyk (2006) analyzed the effect of treatments with mannitol solutions at different concentrations on the hardness of apples and potatoes caused by changes in their structures. Bolanle et al. (2007) conducted an analysis of the texture of cooked and raw pounded yams in terms of cohesiveness, adhesiveness and hardness. Gupta et al. (2007) analyzed the texture of candies with different percentages of sunflower seed in terms of chewiness, hardness, cohesiveness and elasticity.

Fig. 2 Effect of the plantain enzymatic pretreatment employing U and R airflow at different temperatures on the hardness of plantain samples. Data are expressed as mean $\pm$ standard derivation of ten determinations. Different capital letters at the same temperature and different lowercase letters between the temperatures indicate significant difference ($p < 0.05$)

Color

Color is one of the most important quality attributes; it functions as a perceptible indicator of quality. Such perceptible attributes often directly reflect the biochemical composition of the fruit (Lokesh et al. 2014). The results of L^* of all treatments are shown in Fig. 3a. At 65 °C, the sample without enzymatic pretreatment dried with U air flow had the lowest observed L^* value of 70.0, which was significantly different ($p < 0.05$) from the rest of the samples. However, at 50, 65 and 80 °C, all other treatments showed high L^* values, all of which were greater than 75.0 units. While, the degree of darkening found is higher in a sample, the brightness value is lower and vice versa (Prathapan et al. 2009; Di Scala et al. 2011). Therefore, high drying temperatures generated samples with high brightness values, especially in enzymatically treated samples and at 65 °C, either because caramelization and browning due to the Maillard reaction did not occur or

Fig. 3 Effect of the plantain enzymatic pretreatment employing U and R airflow at different temperatures on: **a** L* and **b** h°. Data are expressed as mean $\pm$ standard deviation of three determinations.

because of the effects of drying the product surface as was established by previous reports (Leite et al. 2007; Vega-Gálvez et al. 2008; Di Scala et al. 2011). The hue angle is defined as the starting point on the axis $+a^*$, and this value is expressed in degrees ranging from 0 to 360° counter clockwise. The values of $h^\circ = 0^\circ, 90^\circ, 180^\circ$ and 270° correspond to red, yellow, green and blue, respectively (Lokesh et al. 2014). No significant differences were found ($p > 0.05$) among the temperatures used; all samples were yellow in color at approximately 80°, except untreated samples dried with U air flow, which had h° values of 75.5° at 65 °C (Fig. 3b). However, on average, h° values were higher at 65 °C ($h^\circ = 82.0$) for the rest of treatments at this temperature. Browning is an undesirable feature of conventionally dried foods that were not pretreated and were dried using U air flow. Therefore, convective drying has been used in combination with other methods to reduce the negative effects on color in some foods. This effect has been reported in previous studies by researchers such as Chua et al. (2001), who evaluated the gradual color change during the drying of bananas and observed a general browning in color, in which the tissue changed from yellow to dark red because of drying temperature and time.

Sensory evaluation

The results of sensory evaluation of selected treatments of plantain slices (without enzymatic pretreatment and pretreated with *A. niger*, at 3 temperatures and using R air flow) are shown in Table 2. No significant differences were found ($p > 0.05$) between treatments at 50 °C, where the lowest levels of acceptance by consumers were found (on average, 4.3). No significant difference was found

Different capital letters at the same temperature and different lowercase letters between the temperatures indicate significant difference ($p < 0.05$)

Table 2 Consumer's acceptance of dried plantain slices employing drying with reversal airflow (R)

Treatments	Hedonic score
50 °C untreated	4.1 $\pm$ 1.6 ^b
50 °C <i>A. niger</i>	4.5 $\pm$ 1.8 ^b
65 °C untreated	6.4 $\pm$ 2.0 ^c
65 °C <i>A. niger</i>	7.1 $\pm$ 1.7 ^a
80 °C untreated	6.8 $\pm$ 1.5 ^c
80 °C <i>A. niger</i>	7.0 $\pm$ 1.7 ^a

Mean $\pm$ standard deviation (n = 100). Different letter in superscripts indicate significant difference at $p < 0.05$ level

($p > 0.05$) between plantain samples at 65 and 80 °C pretreated with *A. niger* or between no pretreated samples at 65 and 80 °C, but there was difference between the samples treated with enzymes and without enzymes at 65 and at 80 °C. At these temperatures, a greater acceptability on hedonic scale was found with an average of 7 points which equates to "Like moderately". This degree of acceptance could be influenced by texture characteristics such as porosity and crispness (hardness) of the samples. Although in the analysis of L* and h° there were no significant differences ($p > 0.05$) among most of the treatments, the most visually intense yellow color could have influenced consumer acceptance in the samples of enzymatically treated plantains. Grabert et al. (2001) found better acceptance of dried bananas treated with sulphite due to their lighter color. Leite et al. (2007) found that banana slices that were 0.5 cm thick and dried at 60 °C were more accepted than those that were dried at 70 °C at an air flow of 30 m³/h.

Conclusion

Enzymatic pretreatment followed by drying at three different temperatures with airflow reversal reduced the drying time relative to samples that were not pretreated and dried with unidirectional airflow. Plantain samples pretreated with *A. niger* showed shorter drying times with respect to samples that had been pretreated with *A. aculeatus*. The use of airflow reversal in the samples enzymatically pretreated with *A. niger* at 80 °C had drying times that were 59.0% (208.1 min) shorter than samples dried at 50 °C without enzymatic pretreatment using airflow in one direction. In addition to improving the texture, the products dried at 65 and 80 °C were more accepted by consumers (although the two were not significantly different from each other), but the color of the product dried at 80 °C had deteriorated. This kind of enzymatic pretreatment could allow the conservation of some physical properties and reduction of drying times for plantains relative to the current methodology.

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