Drying Kinetics of Sweet Potato Chips in a Forced Convection Tray-Type Dryer

Leonell P. Lijauco

Abstract—**Drying kinetics of sweet potato chips was investigated in a forced convection tray-type dryer. The drying experiments were performed at different temperatures of the drying air (40, 50 and 60 °C) and air blower velocity (14.336 m/sec, 15.724 m/sec, and 17.212 m/sec), using a constant thickness of 1.5 mm. A constant rate period was not observed in the drying of sweet potato chips; all the drying process occurred in falling rate period. Five thin layer drying models were evaluated and fitting to the experimental moisture data. The fit quality of the models was evaluated using the determination correlation coefficient (R^2), the reduced chi-square (χ^2) and the root mean square error (RMSE). Among the models considered, the Page and Modified Page models gave values of R^2 above 0.99616. These models appear then the most adequate in describing the drying processes of sweet potato chips under the experimental conditions studied. However, both Henderson and Diffusion models gave comparatively higher R^2 values in all cases, whereas the χ^2 and RMSE values were lower; the highest value of R^2 (0.99974) and the lowest values of χ^2 (0.000020) and RMSE (0.004242) were observed for 15.724 m/sec velocity and drying air temperature of 40°C. Thus, these models may be assumed to represent the drying behavior of sweet potato chips in a forced convection tray-type dryer within the experimental study range.**

Index Terms—**drying kinetics, forced convection tray-type dryer, sweet potato chips, thin layer drying models.**

I. INTRODUCTION

Sweet potato (*Ipomoea batatas L.*), locally known as "kamote", is commonly planted in flat to slightly rolling open areas. The crop is known to be a cheap but excellent source of carbohydrates, vitamin A, carotene, calcium, and phosphorus. It is also a fair source of thiamine and iron but a poor source of riboflavin, niacin, and vitamin C.

A versatile crop, sweet potato has multifarious uses. It is not only grown as a food substitute for rice and corn but also as a potential source of raw materials for industrial uses and food delicacies. Sweet potato is being processes into feeds, flour, starch, and pectin for local and export markets. The flour is further processed into fermented products such as soy sauce and alcohol. When freshly cooked it can be saccharified to produce wine, vinegar, and nata [19].

Drying sweet potato safely preserves their vitamins and minerals, while extending their shelf life, when stored in a cool, dark and dry place. Dried until it meets its desired appearance, sweet potato have little amount of water from which enzymes and bacteria can grow. Dried sweet potato are usually uses for culinary purposes. It is made into traditional sweet potato soup, chips and flour.

Conventionally, sweet potato are dried in open air under sunlight by spreading in a single layer on cemented floor, bamboo mat, rock surface or sometimes even on bare earth. Depending upon weather conditions, it takes 2 to 5 days to dry the chips to 13-15% moisture content. Unreliable climatic conditions, however, make continuous sun drying difficult, particularly where the monsoon is of long duration and coincides with time of harvesting. Artificial drying, therefore, becomes essential besides offering saving of time and floor space requirements. It also employs the application of heat from combustion of fossil fuels and biomass resources, directly or indirectly, and in both natural and forced convection systems. Mechanical dryers, long used in developed countries, are finding increased application as farming and grain handling systems develop.

Thin layer drying is an important dehydration technique in food industry. The resulting dried products usually record minimal loss of their native nutritional, chemical and physical qualities while the shelf life and onset of microbial spoilage of the products is extended [4, 20, 22]. Sweet potato is important stable food in Africa, Asia and South America [23, 14, 29, 11]. The uses of these crops have been on the increase even in developed countries such as United States of America, Japan, Australia and New Zealand. The utilization of the crop in virtually every part of the world is indicative of its commercial importance. It is thus necessary to pay attention to means of preserving these food crop over a long period of time with little or no quality change. One way of achieving this goal is to subject the food crop to thin layer drying.

Thin layer drying kinetics is needed for design, operation and optimization of food crops dryers. The falling rate drying period is important in thin layer drying but the exact theoretical basis for moisture diffusion within the materials during the drying process is not fully understood [4, 3, 17]. So thin layer drying kinetics are commonly given as empirical and semi-empirical correlations. Of the fifteen thin layer drying kinetic models available in the literature [3, 17, 1, 26, 23] only Wang and Singh and, geometric models do not contain exponential term. The presence of these exponential terms in majority of the models is indicative of contribution of diffusion mechanism in thin layer drying. Factors such as type and conditions of the crop (morphology, pretreatment, initial moisture content and dimension), drying conditions (temperature, pressure, air-flow rate and humidity) type of dryer (tray, tunnel, fluidized bed, etc) and thermal energy type (hot air, infrared, microwave, etc) employed are known to affect the drying kinetics and qualities of the dried material [18, 4, 17, 1, 6, 26, 20, 22, 27, 28, 15].

Manuscript received May 25, 2017. This research work was supported by the Engineering Research and Development for Technology (ERDT), College of Engineering, University of the Philippines, Diliman, Quezon City, Philippines.

Leonell P. Lijauco is a Faculty Member of Department of Agricultural Engineering, College of Engineering and Technology, Tarlac Agricultural University, Camiling, Tarlac 2306, Philippines (e-mail: lplijauco@yahoo.com).

Forced convection tray-type dryer is simple in construction and operation and can be easily adapted for thin layer drying in farm settlements, most especially, in developing countries like the Philippines. None of the reported works on thin layer drying of sweet potato has been carried out in tray dryer. Therefore, this study is on focused on the investigation of the effect of drying air temperature (40°C, 50°C, and 60°C) and air blower velocity (14.336 m/sec, 15.724 m/sec, and 17.212 m/sec) on the drying kinetics of sweet potato chips using the prototype dryer, and fit the experimental moisture data to various kinetic mathematical models.

II. Material And Methods

A. Experimental Sweet Potato Chips Dryer

The experimental dryer used in this study consists of three basic units: a fan provides the desired drying air blower velocity, electrical heaters that are used to control the temperature of drying air and a drying chamber. A single door was opened on one of the side walls in order to allow the insertion or removal of the drying tray. Air was forced through the dryers using a centrifugal flow blower and the velocity of air was controlled by use of an air control valve. The actual velocity was measured using an air flow meter that was placed 2 cm both above and below the drying tray. Air was heated as it passed through two spiral type electrical heaters that had a heating capacity of 1.0 kilowatt each. These electrical heaters could also be turned off or on separately via a temperature controller in such a way that air temperature could be maintained to within ± 1.0°C of the set value. The hot air was flown straight through the plenum chamber to exit at the wall opposite the entry point. This allowed the hot air to flow both over the drying slices and under the drying trays.

B. Materials

Fresh sweet potato samples were procured in bulk from local market and stored in a refrigerator. To prepare the sweet potato for the drying experiments, they were removed from refrigerated storage and were allowed to equilibrate at ambient environment before being chipped. The samples were then cut into slices of approximately 1.5 mm thick using a sharp stainless steel knife. A caliper was used to check the thickness and uniformity of each slice.

C. Initial Moisture Content Determination

Before the sweet potato chip samples were subjected to drying operation, the initial moisture content was determined using an Oven Method [5].

A twenty-five grams sample was weighed, placed and allowed to dry in an oven at 100°C for 24 hours until the weight did not change any longer. Each determination was performed in triplicate. After drying in the oven, the samples were weighed and recorded. The initial moisture content wet basis was then computed using the following equation:

$$MC_{wb} = \frac{Weight_{initial} - Weight_{final}}{Weight_{initial}} \times 100\%$$

Since moisture content wet basis (MC_{wb}) is usually used in commercial purposes while moisture content dry basis (MC_{db}) is for engineering calculations, for this study it is necessarily to convert MC_{wb} to MC_{db}.

$$MC_{db} = \frac{MC_{wb}}{100 - MC_{wb}} \times 100$$

D. Moisture Content and Drying Rate Observation

The moisture content wet basis at different stages of drying was determined using the initial moisture content wet basis, initial weight, and the final weight of the sample. This was computed using the following equation:

$$W_{initial}(100 - MC_{initial}) = W_{final}(100 - MC_{final})$$

The rate of drying was also observed at different drying temperatures and air blower velocities. This was obtained every 30 minutes for the whole drying operation. The rate of drying was computed by the following equation:

$$Drying\ Rate = \frac{MC_{initial} - MC_{final}}{t_{initial} - t_{final}}$$

E. Drying Temperatures and Blower Velocities

The dryer was evaluated by varying the drying temperatures and air blower velocities. The drying temperatures were 40°C, 50°C, and 60°C respectively; while the air blower velocity levels were 14.336 m/sec, 15.724 m/sec, and 17.212 m/sec respectively. The temperature was measured by a dial thermometer installed in the dryer while the blower velocity was measured at the outlet of the blower using a velocity meter.

F. Experimental Analyses of Drying Sweet Potato Chips

The experimental drying data of sweet potato chips were fitted to five commonly used thin-layer drying models listed in Table 1. In these models, MR represents the dimensionless moisture ratio, namely, $MR = (M - M_e)/(M_0 - M_e)$, where M is the moisture content of the product at each moment, M_0 is the initial moisture content of the product and M_e is the equilibrium moisture content. The values of M_e are relatively small compared with M or M_0 for long drying time. Thus, $MR = (M - M_e) / (M_0 - M_e)$ can be simplified to $MR = M/M_0$ [2, 25].

Table I: Mathematical Models For Drying Curves

No.	Model Name	Model Equation
1	Newton	$MR = \exp(-kt)$
2	Page	$MR = \exp(-kt^n)$
3	Henderson and Pabis	$MR = a \cdot \exp(-kt)$
4	Simplified Fick's Diffusion	$MR = a \cdot \exp(-ct/L^2)$
5	Modified Page	$MR = \exp(-c(t/L^2)^n)$

The goodness of fit of the tested mathematical models to the experimental data was evaluated with the correlation coefficient (R^2), the reduced chi-square (χ^2) and the root mean square error (RMSE). The higher the R^2 values and the lower the χ^2 and RMSE values, the better was the goodness of fit [12, 21]. The reduced chi-square (χ^2) and the root mean square error (RMSE) was calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N - z}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}$$

where $MR_{exp,i}$ was the *i*th experimental moisture ratio, $MR_{pre,i}$ was the *i*th predicted moisture ratio, N was the number of observation and z was the number of constants. In this study, the nonlinear estimation analysis was performed with statistical software.

III. RESULTS AND DISCUSSION

A. Drying Curves Analysis

The drying curves log MR = f(time) of the sweet potato chips for different values of drying air temperature and air blower velocity are shown in Fig. 1-3. The moisture content decreased continuously with drying time. As it is seen from these figures, the drying air temperature and the air blower velocity of the sample have a significant effect on the drying kinetics of sweet potato chips. In effect, an increase in temperature and a decrease in air blower velocity resulted in reduced drying time of the sweet potato chips. The drying times to the average moisture content value of about 10% (db) for 14.336 m/sec velocity were 8, 8, and 12 hours at 60°C, 50°C, and 40°C, respectively. Also as expected, these drying times are longer for air blower velocity of 15.724 m/sec and 17.212 m/sec. The shortest drying time of 6.5 hours was obtained for the air blower velocity of 17.212 m/sec and 60°C temperature.

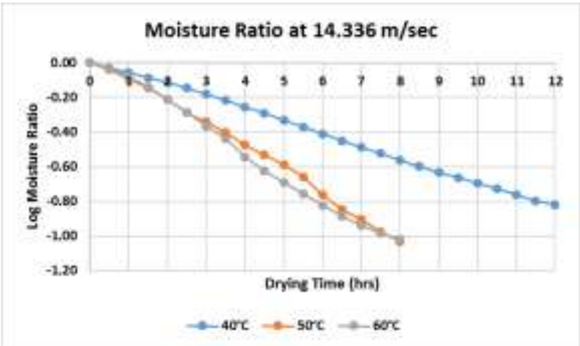

Fig. 1. Moisture ratio versus drying time of sweet potato chips at different temperatures (air blower velocity = 14.336 m/sec).

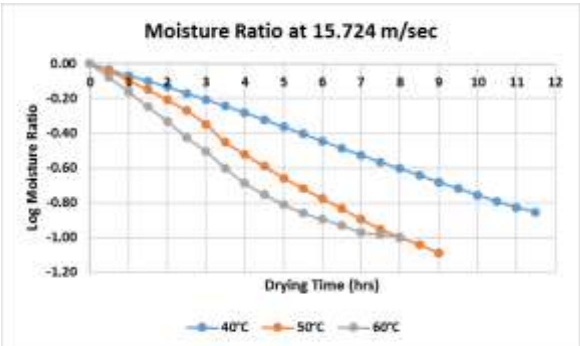

Fig. 2. Moisture ratio versus drying time of sweet potato chips at different temperatures (air blower velocity = 15.724 m/sec).

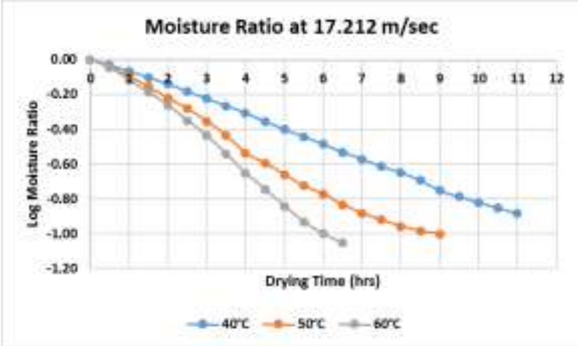

Fig. 3. Moisture ratio versus drying time of sweet potato chips at different temperatures (air blower velocity = 17.212 m/sec).

B. Mathematical Modelling of Drying Curves

The moisture ratio data obtained from the drying experiments were fitted to the 5 mathematical models listed in Table 1. The values of the correlation coefficient (R^2), the reduced chi-square (χ^2) and the root mean square error (RMSE) for different air temperature and air blower velocity determined by non-linear estimation analysis are presented in Table 2; while Table 3 showed the results of the parameters of various thin layer models at different drying air temperature and air blower velocity. As it is seen, the R^2, χ^2 and RMSE values range from 0.97741 to 0.99974, 0.000020 to 0.001765 and 0.004242 to 0.039415, respectively. The high values of correlation coefficient and the low values of reduced chi-square and root mean square error indicate in all cases a good fit. Among the models considered, the Page and Modified Page models gave values of R^2 above 0.99616. These models appear then the most adequate in describing the drying processes of sweet potato chips under the experimental conditions studied. The highest correlation coefficient values and the lowest χ^2 and RMSE values were found for 15.724 m/sec velocity, where the values of R^2 for these models were higher than 0.99900. However, both Henderson and Diffusion models gave comparatively higher R^2 values in all cases, whereas the χ^2 and RMSE values were lower; the highest value of R^2 (0.99974) and the lowest values of χ^2 (0.000020) and RMSE (0.004242) were observed for 15.724 m/sec velocity and drying air temperature of 40°C. Thus, these models may be assumed to represent the drying behavior of sweet potato chips in a forced convection tray dryer within the experimental study range. Among the other mathematical model investigated, the Newton model appears to be the least suitable model for the drying behavior of sweet potato chips.

To determine the effect of different drying conditions on parameters of mathematical models, Fig. 4–7 show the outcome.

Using the Henderson and Pabis model, the a-values were plotted against the drying temperature as shown in Fig. 4. The graph shows that the a-value increases as increases in temperature. At 15.724 m/sec, there is an increase in a-value from 40°C to 50°C. But when reach to 60°C, the a-value becomes 0.991 which is lower than the two temperatures.

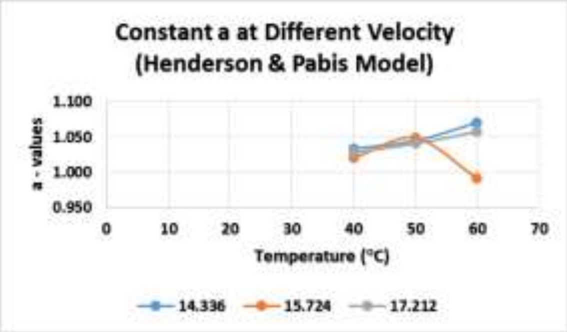

Fig. 4. Effect of different air blower velocity on constant a.

While in Fig. 5, the same trend happened with the drying temperatures of 40°C and 60°C. The a-values decrease from a velocity of 14.336 m/sec to 15.724 m/sec, but increases the a-value from 15.724 m/sec to 17.212 m/sec. The temperature at 50°C differs from the two temperatures. This is due to the unstable air movement inside the drying chamber that was observed during drying operation particularly at the top most tray.

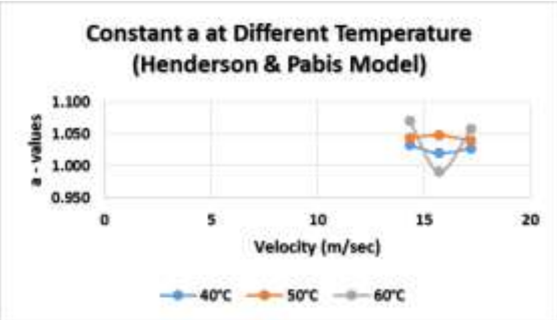

Fig. 5. Effect of different drying temperature on constant a.

On the part of parameter L using Simplified Fick's Diffusion model, Fig. 6–7 show the effect on L-values by varying the drying temperatures as well as the air blower velocity. The L-values on Fig. 6 have the same movement at 15.724 m/sec and 17.212 m/sec. This is also shown in Fig. 7 where the L-values at 50°C and 60°C are all increasing. The velocity of 14.336 m/sec as well as the 40°C temperature differ from the rest drying conditions.

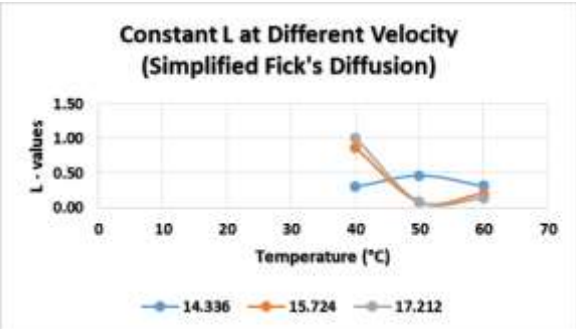

Fig. 6. Effect of different air blower velocity on constant L.

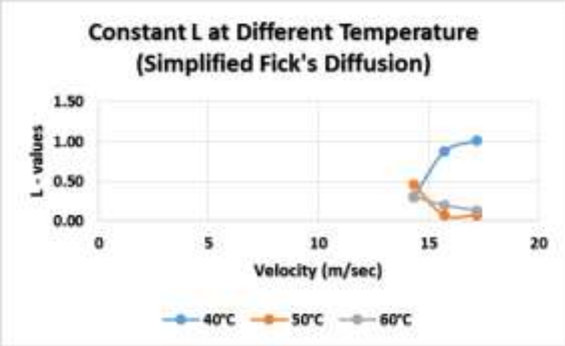

Fig. 7. Effect of different drying temperature on constant L.

C. *Drying Rates Analysis*

The drying rate (DR) is expressed as the amount of the evaporated moisture over time. The drying rates of sweet potato chips were calculated by using:

$$DR = \frac{MC_{t+dt} - MC_t}{dt}$$

where M_t and M_{t+dt} are the moisture content dry basis (percent) at time t and moisture content dry basis at time t + dt (percent), respectively; t is the drying time (hour).

Fig. 8-10 show the changes in drying rate as a function of drying time at the different air temperature and air blower velocity. It is clear that the moisture content and drying rate decrease continuously with drying time. The drying rate was rapid during the initial period but it became very slow at the last stages during the drying process. The moisture content of the material was very high during the initial phase of the drying which resulted in a higher absorption of air temperature and air velocity, and higher drying rates due to the higher moisture diffusion. As the drying progressed, the loss of moisture in the product caused a decrease in the absorption of air drying temperature and air velocity and resulted in a fall in the drying rate. Constant drying rate period was not observed during the drying of sweet potato chip samples. Because practically all agricultural drying takes place in the falling-rate period. Products that are moved into a dryer from a washer may experience a short initial constant-rate period. This period is usually minor when compared to the complete drying process and can be neglected in the calculations.

The falling-rate period is bounded by equilibrium moisture contents of an equilibrium moisture curve between zero and nearly 100% relative humidity. Moisture contents near the 100% level would be in the constant rate period. The 100% equilibrium point is not a satisfactory procedure for determining the exact critical moisture content since equilibrium moisture data observed above 95% relative humidity are usually unreliable [16].

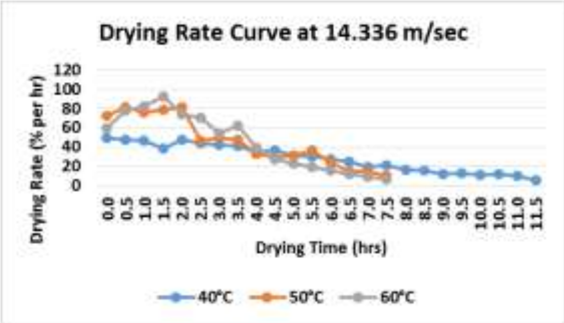

Fig. 8. Drying Rate versus Drying Time at Different Temperatures (Air Blower Velocity = 14.336 m/sec).

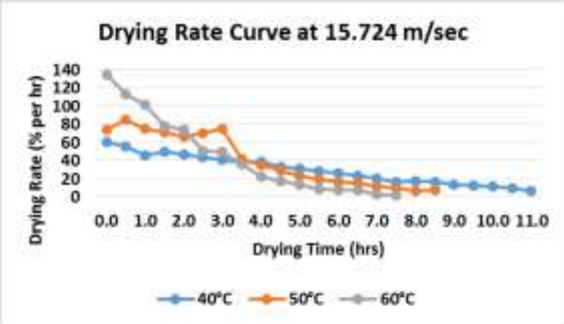

Fig. 9. Drying Rate versus Drying Time at Different Temperatures (Air Blower Velocity = 15.724 m/sec).

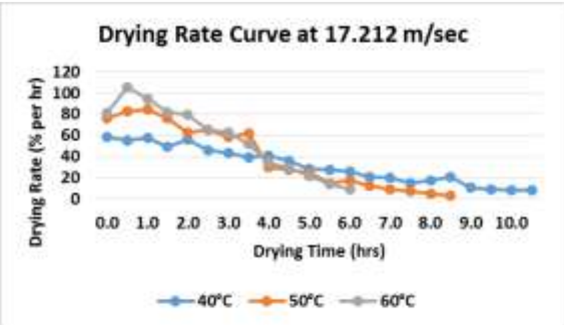

Fig. 10. Drying Rate versus Drying Time at Different Temperatures (Air Blower Velocity = 17.212 m/sec).

IV. Conclusion

The moisture content decreased continuously with drying time. As shown from the figures presented, the drying air temperature and the air blower velocity of the sample have significant effect on the drying kinetics of sweet potato chips. In effect, increasing the temperature and increasing in air blower velocity resulted in reduced drying time and increased draying rate, and vice versa. Among the various mathematical models considered, the Page and Modified Page models gave values of R^2 above 0.99616. These models appear the most adequate in describing the drying processes of sweet potato chips.

Acknowledgment

The author would like to acknowledge his dissertation advisers, Dr. Edwin N. Quiros and Dr. Rizalinda L. De Leon, for the never-ending help, guidance, and support throughout research and graduate studies. He also acknowledged ERDT-DOST, for granting Ph.D. Scholarship. Lastly, he expressed his deep gratitude to the Tarlac Agricultural University for giving opportunity to pursue Ph.D. degree.

References

[1] D. K. Akal, D. A. Kahveci, and A. Cihan, "Mathematical modeling of drying of rough rice in Stacks", *Food Science and Technology International*, 13 (6): 437-445, 2007.

[2] N. A. Akgun and I. Doymaz, "Modeling of olive cake thin-layer drying process", *Journal of Food Engineering*, 68: 455–461, 2005.

[3] E. K. Akpinar, "Mathematical modeling of thin–layer drying process under open sun of some aromatic plants", *Journal of Food Engineering*, 77 (4): 864-870, 2006.

[4] E. K. Akpinar and Y. Bicer, "Mathematical modeling of thin layer drying process of long green pepper in solar dryer and under open sun, *Energy Conversion and Management*, 49 (6): 1367-1375, 2008.

[5] AOAC, *Official methods of analysis*. 12th Edition. Association of Official Analytical Chemists. Washington, D.C, 1975.

[6] S. B. Bakal, G. P. Sharma, S. P. Sonawane, and R. C. Verma, "Kinetics of potato drying using fluidized bed dryer", *doi*: 10.1007/s13197-011-0328-x, 2011.

[7] L. M. Diamante and P. A. Munro, "Mathematical modeling of hot air drying of sweet potato slices", *International Journal of Food Science and Technology*, 26 (1): 99-109. 1991.

[8] L. M. Diamante and P. A. Munro, "Mathematical modeling of the thin layer solar drying of sweet potato slices", *Solar Energy*, 51 (4): 271-276, 1993.

[9] I. Doymaz, "Thin-layer drying characteristics of sweet potato slices and mathematical modelling", *Heat and Mass Transfer* doi: 10.1007/s00231-010-0722-3, 2010.

[10] I. Doymaz, "Infrared drying sweet potato (*Ipomoea batatas L.*) slices", *Journal of Food Science and Technology*, doi: 10.1007/s13197-010-0217-8, 2011.

[11] R. Engone, J. Mugisha, and H. Bashaasha, "Tuber utilization options among sweet potato producers in Eastern Uganda", *African Crop Science Proceedings*, 7: 715-719, 2005.

[12] C. Ertekin and O. Yaldiz, "Drying of eggplant and selection of a suitable thin layer drying model, *Journal of Food Engineering*, 63: 349–359, 2004.

[13] K. O. Falade and O. J. Solademi, "Modeling of air drying of fresh and blanched sweet potato slices", *Int Journal of Food Science and Technology*, 45 (2): 278-284, 2010.

[14] O. P. Fawole, "Constraints to production, processing and marketing of sweet potato in selected communities in Offa Local Government Area, Kwara State, Nigeria", *Journal of Human Ecology*, 22 (1):23-25, 2007.

[15] H. R. Gazor and A. Mohsenimanesh, "Modeling drying kinetics of canola in fluidized bed dryer", *Czech Journal Food Science*, 28 (6): 531-537, 2010.

[16] S. M. Henderson and R. L. Perry, *Agricultural Process Engineering*, 3rd Edition, The AVI Publishing Company, Inc. Westport, Connecticut, 1976, pp. 302-335.

[17] H. O. Menges and C. Ertekin, "Mathematical modeling of thin layer drying of golden apples", *Journal of Food Engineering*, 77 (1): 119-125, 2006.

[18] J. Mitra, S. L. Shrivastava, and P. S. Rao, "Onion dehydration: A review", *Journal of Food Science and Technology*, doi: 10.1007/s13197-011-0369-1, 2011.

[19] NRRDEN, "Halamang ugat (kamote, balinghoy, ubi at ibang halamang ugat) - The philippine national program on root crops research and development", *National Root Crop RDE Network*, Philippines, p 62, 1999.

[20] T. Orikasa, L. Wu, Y. Ando, Y. Murawatsu, P. Roy, T. Yario, T. Shina, A. Tagawa, "Hot air drying characteristics of sweet potato using moisture sorption isotherm analysis and its quality changes during drying", *International Journal of Food Engineering*, 6(2), Article 12, 2010.

[21] M. Özdemir and Y. O. Devres, "The thin layer drying characteristics of hazelnuts during roasting", *Journal of Food Engineering*, 42, 225–233, 1999.

[22] S. S. Sablani, "Food quality attributes in drying", *Stewart Postharvest Review*, 2: 8, 2006.

[23] N. J. Singh and R. K. Pandey, "Thin layer drying kinetics of sweet potato cubes", *IE (1) Journal-AG*, 91: 24-31, 2010.

[24] D. L. Tan, S. K. Miyamoto, K. Ishibashi, K. Matsuda and T. Satow, "Thin layer drying of sweet potato chips and pressed grates", *Transactions of ASABE*, 44 (3): 669-674, 2001.

[25] N. J. Thakor, S. Sokhansanj, F. W. Sosulski and S. Yannacopoulos, "Mass and dimensional changes of single canola kernels during drying", *Journal of Food Engineering*, 40: 153–160, 1999.

[26] T. Y. Tunde-Akintunde and A. Ayala, "Air-drying characteristics of chili pepper", *International Journal of Food Engineering*, 6 (1): Article 7, 2010.

[27] D. Velic, M. Bilic, S. Tomas, M. Planinic, A. Bucic-Kojic, and K. Aladic, "Study of the drying kinetics granny smith apple in fluid bed dryer", *Agric. Conspectus Scientifics*, 72 (4): 323-328, 2007a.

[28] D. Velic, M. Bilic, S. Tomas, M. Planinic, A. Bucic-Kojic, and K. Aladic, "Study of the drying kinetics of granny smith apple in tray dryer", *Agric. Conspectus Scientificus*, 72 (4): 329-334, 2007b.

[29] J. A. Woolfe, "Sweetpotato: An untapped food resource", *Cambridge: Cambridge University Press*, 1992.

Leonell P. Lijauco was born in Manila, Philippines, in 1971. He received the B.S. and M.S. degrees in agricultural engineering from the University of the Philippines Los Baños, Laguna, Philippines, in 1994 and 2000 respectively, and the Ph.D. degree in energy engineering from the University of the Philippines Diliman, Quezon City, Philippines, in 2016.

In 1994, he joined the Agricultural and Bioprocess Division, Institute of Agricultural Engineering, College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, as a University Research Associate. His areas of research interest are processing of pelletized organic fertilizer, processing of pelletized feeds for animal consumption, development and testing of recirculating flow dryer, development and testing of machines for feeds and organic fertilizer, development and testing of equipment for ginger processing, development and testing of heat pump dryer for high value crops, flowers and foliage, and feasibility study on atchuete thresher technology. Due to his eagerness to impart his knowledge, he resigned and joined the Department of Agricultural Engineering, College of Engineering and Technology, Tarlac Agricultural University in 2003. He has been with the department, where he was an Instructor, became an Assistant Professor in 2009, and an Associate Professor in 2011. His current research interests include agricultural process engineering and technology, root crops processing, development and testing of machines for postharvest processing, and biomass energy.

Dr. Lijauco is a member of the Philippine Society of Agricultural Engineers (PSAE), University of the Philippines Alumni Engineers (UPAE), and International Society for Southeast Asian Agricultural Sciences, Inc. (ISSAAS) Philippine Chapter. He was a National Awardee of the Civil Service PAGASA Award (Group Category) in 2008 and a recipient of the Engineering Research and Development for Technology (ERDT) Scholarship in 2009.

TABLE II: STATISTICAL RESULTS OF THE MATHEMATICAL MODELS AT DIFFERENT DRYING CONDITIONS.

MODEL	TEMP °C	VELOCITY								
		14.336 m/s			15.724 m/s			17.212 m/s		
		R^2	χ^2	RMSE	R^2	χ^2	RMSE	R^2	χ^2	RMSE
Newton	40	0.99536	0.000332	0.017863	0.99806	0.000138	0.011490	0.99711	0.000215	0.014335
	50	0.99251	0.000648	0.024704	0.99120	0.000784	0.027251	0.99268	0.000632	0.024474
	60	0.98324	0.001585	0.038621	0.99329	0.000528	0.022292	0.98611	0.001337	0.035241
Page	40	0.99927	0.000054	0.007068	0.99974	0.000020	0.004242	0.99965	0.000027	0.004989
	50	0.99943	0.000052	0.006795	0.99727	0.000258	0.015191	0.99616	0.000351	0.017723
	60	0.99716	0.000286	0.015896	0.99474	0.000442	0.019748	0.99948	0.000055	0.006838
Henderson and Pabis	40	0.99750	0.000187	0.013102	0.99883	0.000087	0.008933	0.99854	0.000114	0.010194
	50	0.99571	0.000396	0.018682	0.99443	0.000525	0.021684	0.99501	0.000457	0.020213
	60	0.99035	0.000974	0.029315	0.99341	0.000553	0.022097	0.99124	0.000914	0.027992
Simplified Fick's Diffusion	40	0.99750	0.000195	0.013102	0.99883	0.000091	0.008933	0.99854	0.000119	0.010194
	50	0.99571	0.000424	0.018682	0.99442	0.000559	0.021695	0.99500	0.000485	0.020215
	60	0.99035	0.001043	0.029315	0.99341	0.000593	0.022097	0.99124	0.000997	0.027992
Modified Page	40	0.97741	0.001765	0.039415	0.99974	0.000021	0.004242	0.99965	0.000029	0.004989
	50	0.99943	0.000056	0.006795	0.99727	0.000274	0.015191	0.99616	0.000373	0.017723
	60	0.99716	0.000307	0.015896	0.99474	0.000474	0.019748	0.99948	0.000060	0.006838

TABLE III. PARAMETERS OF THE MATHEMATICAL MODELS AT DIFFERENT DRYING CONDITIONS.

MODEL	TEMP °C	VELOCITY											
		14.336 m/s				15.724 m/s				17.212 m/s			
		k	n	a	L	k	n	a	L	k	n	a	L
Newton	40	0.154541	-	-	-	0.168737	-	-	-	0.182511	-	-	-
	50	0.269813	-	-	-	0.280182	-	-	-	0.280617	-	-	-
	60	0.286617	-	-	-	0.372822	-	-	-	0.341660	-	-	-
Page	40	0.126782	1.108091	-	-	0.149325	1.069011	-	-	0.157411	1.086567	-	-
	50	0.218344	1.155552	-	-	0.228459	1.149075	-	-	0.241701	1.109459	-	-
	60	0.209709	1.238547	-	-	0.400711	0.935984	-	-	0.261250	1.235728	-	-
Henderson and Pabis	40	0.160684	-	1.033293	-	0.172702	-	1.019984	-	0.188420	-	1.028072	-
	50	0.282902	-	1.044462	-	0.294237	-	1.048172	-	0.292575	-	1.040412	-
	60	0.307828	-	1.070395	-	0.369230	-	0.991000	-	0.362411	-	1.057693	-
Simplified Fick's Diffusion	40	0.014141	-	1.033297	0.296652	0.131898	-	1.019984	0.873918	0.193348	-	1.028072	1.012994
	50	0.060653	-	1.044462	0.463030	0.001654	-	1.049980	0.074875	0.001851	-	1.041230	0.079512
	60	0.029692	-	1.070396	0.310573	0.015182	-	0.991009	0.202777	0.006879	-	1.057742	0.137766
Modified Page	40	0.000299	0.866629	-	0.023873	0.265645	1.069012	-	1.309210	0.295923	1.086567	-	1.337060
	50	0.078018	1.155548	-	-0.640631	0.190375	1.149075	-	0.923716	0.305635	1.109459	-	1.111563
	60	0.056807	1.238548	-	0.590222	0.128817	0.935985	-	0.545402	0.042170	1.235729	-	-0.478100