

การพัฒนาแบบจำลองทางคณิตศาสตร์และโปรแกรมคอมพิวเตอร์สำหรับทำนายเวลาที่ใช้ในการทำแห้งส่วนต่างๆ ของต้นยอ

THE DEVELOPMENT OF MATHEMATICAL MODEL & COMPUTER PROGRAM IN THE PREDICTION OF DRYING TIME FOR VARIOUS PARTS OF *MORINDA SP.*

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บทคัดย่อ: นำใบ, เปลือก, ลำต้น และรากของต้นยอมาศึกษาจลนพลศาสตร์การทำแห้งแบบถาดและฟลูอิดไดซ์เบด ด้วยแบบจำลองทางคณิตศาสตร์ 4 แบบ ที่โยงความสัมพันธ์ระหว่างอัตราการแห้ง (R , $\text{kg}_{\text{น้ำ}}/\text{ชั่วโมง}$) และปริมาณความชื้นอิสระ (FMC, $\text{kg}_{\text{น้ำ}}/\text{kg}$ มวลแห้ง) แบบจำลองที่หนึ่งและสองกำหนดให้อัตราการทำแห้งในช่วง falling rate คงที่ แต่ต่างกันที่การบังคับพิกัด (R , FMC) ให้ผ่านและไม่ผ่านจุด (0, 0) ส่วนแบบจำลองที่สามและสี่ใช้สำหรับการทำแห้งชนิด diffusion และ capillary-controlled แบบจำลองที่สองทำนายผลการทดลองได้ดีที่สุด โดยมีค่า (RSS, R^2) เท่ากับ (2.53×10^{-4} , 0.8980) สำหรับใบ, (2.80×10^{-2} , 0.8477) สำหรับเปลือก, (2.87×10^{-3} , 0.9725) สำหรับลำต้น และ (1.20×10^{-2} , 0.9281) สำหรับรากต้นยอ ในส่วนการทำแห้งด้วยเครื่องฟลูอิดไดซ์เบด แบบจำลองที่สี่ทำนายผลการทดลองได้ดีที่สุดด้วยค่า (RSS, R^2) เท่ากับ (6.89×10^{-3} , 0.9787) สำหรับลำต้น และ (2.61×10^{-4} , 0.9992) สำหรับราก แล้วสร้างโปรแกรม VBA6.3 ใน EXCEL2003 เพื่อทำนายเวลาทำแห้งใบ เปลือก ลำต้น และรากต้นยอ

Abstract: Leaves, barks, stems and roots of Indian mulberry tree were studied for the drying kinetics in a tray and fluidized-bed dryers. Four mathematic models which correlated the rate of drying (R , $\text{kg}_{\text{water}}/\text{h}$) and free moisture content (FMC, $\text{kg}_{\text{water}}/\text{kg}_{\text{dry mass}}$) were investigated. The drying rate during the region of falling rate was kept constant in each of the first two models. The difference between both models was whether the coordinate (R , FMC) was forced to pass the origin (0, 0) (model 1) or not (model 2). The third and fourth models were employed for diffusion and capillary-controlled drying kinetics. The second drying model provided the best prediction of experimental data with (RSS, R^2) values of (2.53×10^{-4} , 0.8980) for the leaves, (2.80×10^{-2} , 0.8477) for the barks, (2.87×10^{-3} , 0.9725) for the stems and (1.20×10^{-2} , 0.9281) for the roots. In fact, the fourth model was found to be the best predictor of drying kinetics in the fluidized bed dryer with (RSS, R^2) of (6.89×10^{-3} , 0.9787) for the stems and (2.61×10^{-4} , 0.9992) for the roots. The drying times of various mulberry tree parts were subsequently predicted by the developed computer program VBA6.3 in EXCEL2003.

Introduction: At the present, anthraquinone plays an important role in the pulping industry where the conventional method of paper pulping is usually carried out by a mechanical means. Six years ago Patt *et al.* (2001) reported the enhancement of paper pulping efficiency by the application of anthraquinone as a co-catalyst with alkaline sulfite to achieve delignification. In addition, The Natural Resource Ministry of Georgia State (2005) also described the positive effects of anthraquinone in speeding up of reaction, yield improvement and reduction in chemical usages by up to 10%. Furthermore, the chemical compounds with similar structure to anthraquinone also possessed the anti-tumor and anti-cancer properties (Loadman & Calabrese 2001). The aims of this research project were to

- 1) develop mathematical models for drying kinetics of various *Morinda* sp. parts using tray and fluidized bed dryers,
- 2) design computer subroutines in Visual Basics for Microsoft®EXCEL to create drying curves of the desired parts of plant from the input initial conditions and moisture contents as well as to predict the drying time of an individual part of plant.

Methodology: Leaves, barks, stems and roots of *Morinda* sp. were collected from Amphoe Muang, Sarapee, Mae Rim of Chiang Mai province. Each sample was stored in a plastic bag prior to rapid freezing with air blast freezer (Faculty of Agro-Industry, Chiang Mai Province) at -20°C. The pre-drying procedure was carried out by placing the frozen samples in a refrigerator for the period of 24 h and subsequently in the 35°C incubator (Memmert, Model No. 400) for 15 (leaves) or 30 (other parts) min. The suitable size reduction method was then performed on each part of the plant. The procedure was repeated twice. Tray drying was carried out at 65°C with air flow rate of 1 m s⁻¹ while fluidized bed dryer was employed to dry 100 g of sample with air flow rate of 5.7 m s⁻¹. Visual Basic for Applications (VBA) version 6.3 in Microsoft® EXCEL 2003 was used in the design of drying time predicting program. The calculations of errors and 95% confidential interval were based on linear regression suggested by Bates & Watts (1988). The following five equations (Geankoplis 2003) were used in the analyses of drying curves and drying time;

$$R = \left\{ \begin{array}{ll} \left(\frac{R_{\max}}{X_c} \right) x & ; \quad x \leq X_c \\ R_{\max} & ; \quad x > X_c \end{array} \right\} \quad (1) \quad R = \left\{ \begin{array}{ll} ax + b & ; \quad x \leq X_c \\ aX_c + b & ; \quad x > X_c \end{array} \right\} \quad (2)$$

$$R = \left\{ \begin{array}{ll} ax^2 + bx + c & ; \quad x \leq X_c \\ aX_c^2 + bX_c + c & ; \quad x > X_c \end{array} \right\} \quad (3) \quad R = \left\{ \begin{array}{ll} ax^3 + bx^2 + cx + d & ; \quad x \leq X_c \\ aX_c^3 + bX_c^2 + cX_c + d & ; \quad x > X_c \end{array} \right\} \quad (4)$$

$$t_{dry} = \frac{M}{A} \int \frac{1}{R} dX \quad (5)$$

Results, Discussion and Conclusion: The analysis of drying kinetics in a tray dryer showed that the second equation for drying provided the best prediction with (RSS, R²) of (2.53 × 10⁻⁴, 0.8980) for leaves, (2.80 × 10⁻², 0.8477) for barks, (2.87 × 10⁻³, 0.9725) for stems (Fig. 1) and (1.20 × 10⁻², 0.9281) for roots of *Morinda* sp. The statistical analysis of each case was summarized in Table 1. This was compared to the fourth equation that yielded the best prediction for drying in the fluidized bed dryer with (RSS, R²) of (6.89 × 10⁻³, 0.9787) for stems and (2.61 × 10⁻⁴, 0.9992) for roots (Fig. 2). In addition, the developed computer subroutines (Fig. 3) could be used efficiently in the prediction of the drying time, in which,

the user was required to enter dryer type, weight of the dried mass, drying area, initial and final moisture contents of the corresponding part of the plants to be analyzed.

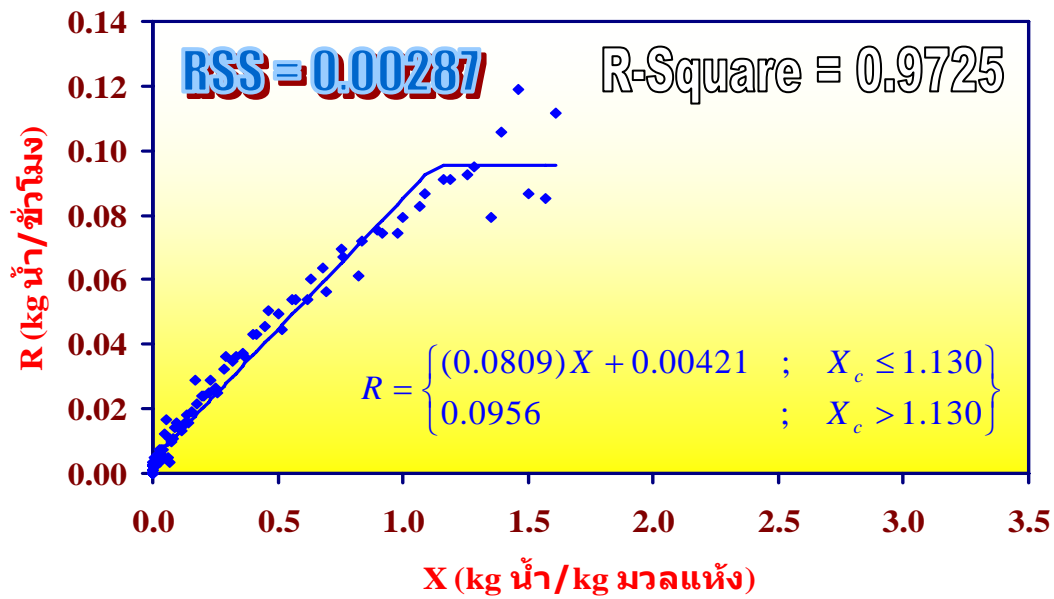


Fig. 1: Drying kinetics of stems in the tray dryer

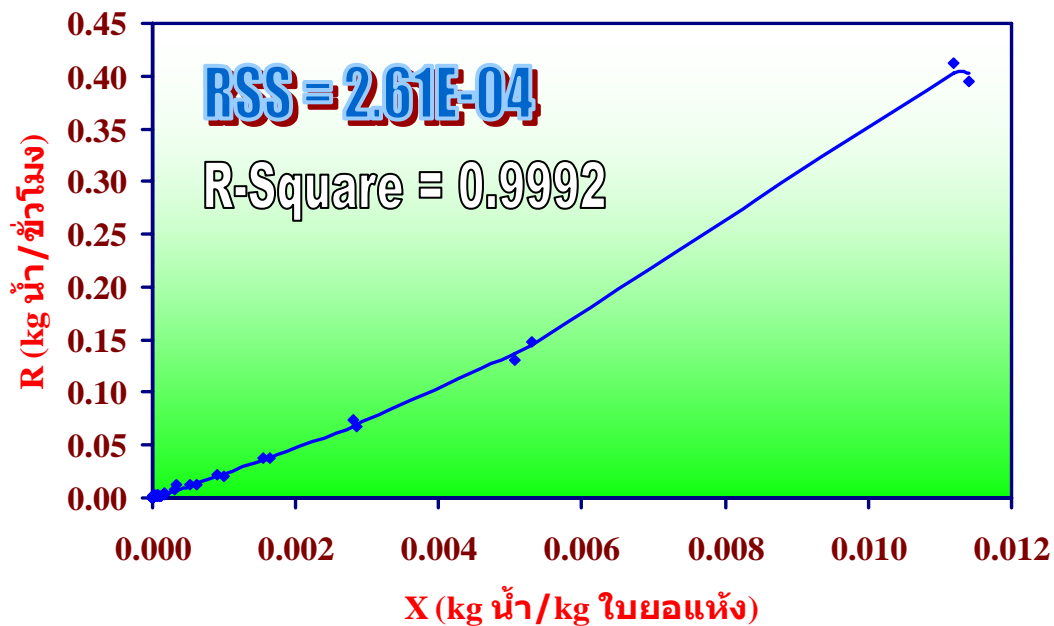


Fig. 2: Drying kinetics of roots in the fluidized bed dryer

Table 1: Statistical analysis of related variables/parameters in Equation 2 for drying kinetics in a tray dryer.

Statistical Variables/ Parameters	Parts of <i>Morinda</i> sp.			
	Leaves	Barks	Stems	Roots
Equation #	2	2	2	2
RSS	0.000253	0.028	0.00287	0.012
R ²	0.8980	0.8477	0.9725	0.9281
R _{max} (kg _{water} /h)	0.0138 ± 0.0025	0.0902 ± 0.0157	0.0956 ± 0.0068	0.0847 ± 0.0126
a (kg _{dried mass} /h)	0.00886 ± 0.00123 95% C.I. (0.00886 ± 0.00248)	0.130 ± 0.016 95% C.I. (0.130 ± 0.033)	0.0809 ± 0.0038 95% C.I. (0.0809 ± 0.0077)	0.107 ± 0.012 95% C.I. (0.107 ± 0.024)
B (kg _{water} /h)	0.00100 ± 0.00056 95% C.I. (0.00100 ± 0.00113)	0.00505 ± 0.00438 95% C.I. (0.00505 ± 0.00878)	0.00421 ± 0.00147 95% C.I. (0.00421 ± 0.00296)	0.00432 ± 0.00355 95% C.I. (0.00432 ± 0.00712)
X _c (kg _{water} /kg _{dried mass})	1.44 ± 0.20 95% C.I. (1.44 ± 0.40)	0.655 ± 0.080 95% C.I. (0.655 ± 0.160)	1.13 ± 0.06 95% C.I. (1.13 ± 0.12)	0.749 ± 0.075 95% C.I. (0.749 ± 0.151)

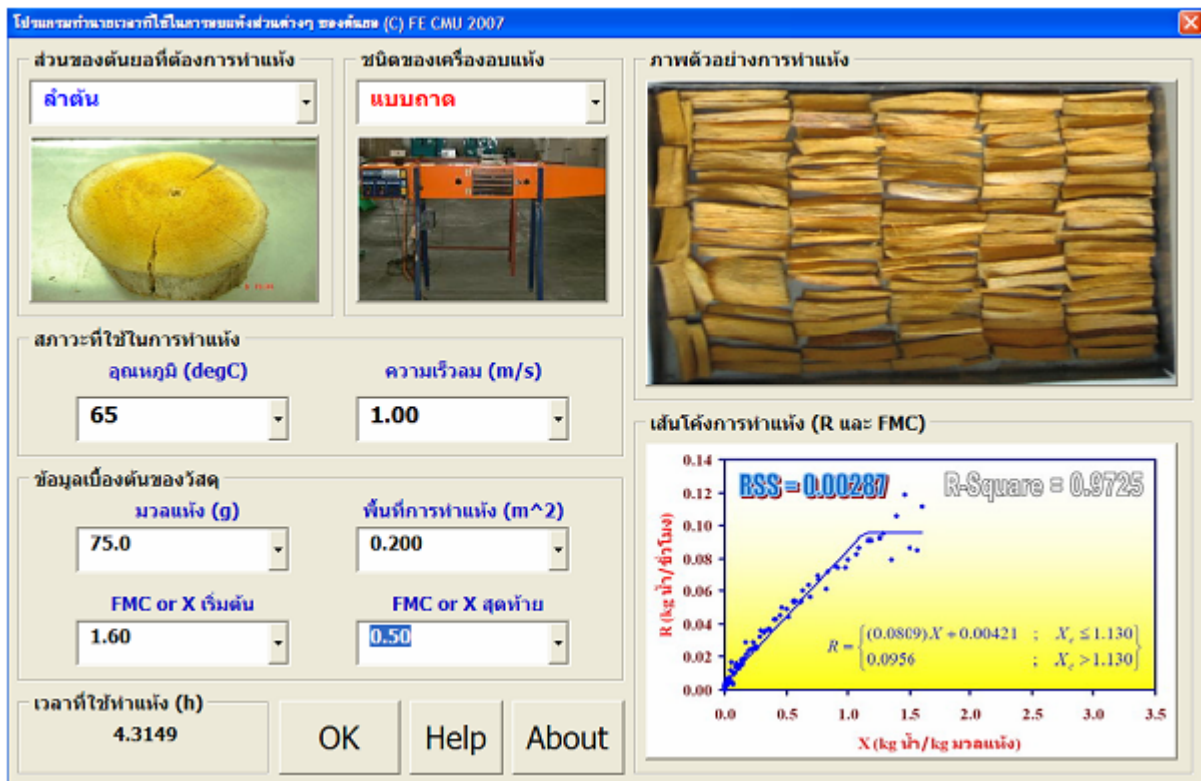


Fig. 3: Developed computer subroutines for prediction of *Morinda* sp. drying time

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Keywords: Drying curve, VBA, *Morinda* sp., Kinetics, Mathematical Model

Acknowledgements: The research team would like to express our gratitude to Chiang Mai University who provided us with the funding support (New Researcher Grant, 2005).