สมการอบแห้งชั้นบางและการเปลี่ยนแปลงค่าสีของขึ้นช่ายภายใต้อุณหภูมิการอบแห้งที่แตกต่างกัน

Thin layer drying equation and the changes in color of celery under different drying temperatures

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Abstract

Celery is a kind of vegetable which has an essential oil and is used in a number of dishes to enhance the good taste. However, fresh product has a short shelf life. The objective of this research was to study the effect of drying temperature on moisture content and color and to find the empirical drying equation as function of drying temperature and time. Celery was divided into three parts of leave, stems and roots due to different moisture content of each part. Samples were conducted at the drying temperature of 40, 50, and 60 °C in a thin layer dryer at a constant air velocity of 1 m/s. The experimental data were fitted into Newton, Page's, Two-term, Handerson and Pabis, and Logarithmic drying model. The results found that the best fit for celery drying was Logarithmic model which was the same in three parts. The drying rate increased with the drying temperature and it was shown that the root part had the highest drying rate. For the color assessment, the L* (lightness) value decreased and a* (redness) value increased with the increase of drying temperature in all parts of dried celery except the b* (yellowness) value that increased in roots and stems part.

Keywords : quality, essential oil, thin layer dryer, drying kinetics

บทคัดย่อ

ขึ้นช่ายเป็นผักที่มีน้ำมันหอมระเหยและใช้ในการปรุงแต่งอาหารหลายชนิดเพื่อเพิ่มรสชาติ ขึ้นช่ายสดมีอายุการเก็บรักษาสั้น งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาผลของอุณหภูมิการอบแห้งต่อความชื้นและค่าสีของขึ้นช่ายและหาสมการการอบแห้งเอมไพริเคิลที่เป็นฟังก์ชันกับอุณหภูมิและเวลาในการอบแห้ง โดยแบ่งขึ้นช่ายออกเป็น 3 ส่วน ได้แก่ ใบ ลำต้น และราก เนื่องจากความชื้นในแต่ละส่วนแตกต่างกัน ตัวอย่างขึ้นช่ายจะนำไปอบแห้งด้วยเครื่องอบแห้งแบบชั้นบางที่อุณหภูมิ 40 50 และ 60 องศาเซลเซียส ที่ความเร็วลมคงที่ 1 เมตร/วินาที ข้อมูลจากการทดลองนำมาฟิตกับสมการ Newton Page's Two-term Handerson and Pabis และ Logarithmic ผลการทดลองพบว่าสมการที่ทำนายอัตราการอบแห้งได้ดีที่สุดทั้งส่วน ลำต้น ราก และใบ คือ Logarithmic อัตราการอบแห้งเพิ่มขึ้นตามอุณหภูมิการอบแห้งและพบว่าส่วนรากมีอัตราการอบแห้งสูงสุด สำหรับด้านค่าสี ค่า L* (ความสว่าง) และ ค่า a* (ความเป็นสีแดง) เพิ่มขึ้นในทุกส่วนของขึ้นช่าย ยกเว้น ค่า b* (ความเป็นสีเหลือง) เพิ่มขึ้นเฉพาะในส่วนรากและลำต้นเมื่ออุณหภูมิการอบแห้งเพิ่มขึ้น

คำสำคัญ : คุณภาพ น้ำมันหอมระเหย เครื่องอบแห้งแบบชั้นบาง จลนพลศาสตร์การอบแห้ง

Introduction

Celery is a plant of *Apium graveolens* Linn. belonging to the Apiaceae family. In Thailand, there are two types of celery found in supermarket which are Chinese and European celery. Chinese celery is widely planted in Asian region which is smaller than regular celery. Celery is a plant used for culinary and medical uses. It is a flavoring vegetable using for making soup, salad and cuisine to improve the taste due to the presence of essential oil in plant (Wilson, 1970). Fresh celery need to be stored at cool temperature to prolong shelf life, it can be kept for 5-7 weeks at 0-2 °C (Cantwell and Suslow, 2002). However, the convenient life of consumer in rush hour prefers the ready to use product.

The first quality judgment by consumer is its appearance. The color of agricultural products can be changed during thermal processing. As plant material undergoes through hot air drying may cause the quality

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degradation due to color reaction and decomposition of active ingredient (Arabhosseini et al., 2001; Maskan, 2001 and Arslan and Ozcan, 2008).

High moisture content of perishable commodity has a very short shelf life. It is needed to reduce the moisture content down to safe level before storage or further process. Drying with hot air is a conventional process used widely to remove water from commodities. Each plant gave a different drying kinetics due to the various compositions which affected to the moisture migration (Krokida et al., 2003; Davidson et al., 2004; Manges and Ertekin, 2006; Doymaz et el., 2006 and Tarigan et al., 2007). Even in the same agricultural produce, the different part of plant had different moisture content. The non-uniform of moisture content was due to the different tissue in each part. In order to predict the drying time that was required to reduce the high moisture content to the safe storage of celery. The objective of this work was to study drying kinetics of celery from different part. The best fit of the drying equation was also predicted. The quality in color change was evaluated.

Materials and Methods

Sample preparation

Chinese celery was purchased from local market in Mahasarakham Province. Then, it was washed and drained the excess water, then left at room temperature on a screen. Sample was divided by cutting into different parts of leaves, roots and stems which was 5 cm in length. The initial moisture content was determined using hot air oven method at 60 °C for 72 hr.

Drying condition and thin layer drying equation fitting

Sample was dried by thin layer at the drying at the temperatures of 40, 50 and 60 °C with a constant air velocity of 1 m/s. 10 g of sample was placed on a screen tray and put in a drying chamber after the drying temperature reach to the setting point. The initial exact weight was recorded. Then, sample was taken to weight at the elapsed time of 3, 6, 9, 12, and 15 min, then every 5 min until 60 min followed by every 10 min until constant weight of drying. The data between drying rate versus drying time was plotted. For the equilibrium moisture content of each condition was obtained by static method to calculate the moisture ratio (MR) as given.

$$MR = \left(\frac{M_t - M_e}{M_i - M_e} \right)$$

The experimental drying data from all parts of celery were compared with the published drying models namely: Newton, Page's, Henderson and Pabis, two – term exponential and logarithmic (Akpinar, 2006; Doymaz, 2006; Doymaz et al., 2006 and Menges and Ertekin, 2006) as shown in Table 1.

The constants of drying equations were function with drying temperature in form of second degree of polynomial. The best fit of experimental data was compared with model by multiple regressions. Evaluation between experimental and theoretical data was calculated by coefficient of determination (R^2), Chi-square (χ^2) and sum of square error (SSE).

Color assessment

The colorimetric data used to characterize the color of samples were L*, a* and b* from hunter scale using Mini Scan XE Plus. It was measured before and after drying. The data was evaluated in term of color change for each value (for example ΔL*= L*before drying –L*after drying).

Results and Discussion

The drying rate of celery leaves, stems and roots under drying temperature of 40, 50 and 60 °C was studied. The results found that the drying rate in all parts increased with the increasing of drying temperature which was agreed with the previous research (Krokida et al., 2003; Doymaz et al., 2006 and Doymaz, 2006). The higher temperature accelerated the moisture migration in biomaterial as its structure sensible to heat. The result was expressed that the drying rates in all parts are difference, this might be the different initial moisture content (data not shown). The celery roots had a faster drying rate than leaves and stems, respectively. Apart from the different initial moisture content, the structure of each part is composed with different tissue and density, resulting in the difference of moisture removal.

The moisture ratios obtained experimentally were compared with theoretical models by multiple regression. R^2 , χ^2 and SSE were calculated for each model in all parts of celery and compared to find the best fit between theoretical and experimental data. The statistical results are presented in Table 1. It appears that in all parts, the logarithmic describes more accurately the drying behaviour (highest R^2 and lowest χ^2 and SSE).

Table 1. Statistical results of five models of different parts of celery drying.

Model	Equations	Celery part	R^2	χ^2	SSE
Newton	MR = $\exp^{(-kt)}$	stem	0.981458	0.001807	0.247495
		leave	0.981004	0.001998	0.201843
		root	0.974157	0.002698	0.167302
Page's	MR = $\exp^{(-kt^n)}$	stem	0.984591	0.001535	0.205684
		leave	0.990870	0.001000	0.097023
		root	0.994995	0.000549	0.032403
Two – Term Exponential	MR = a $\exp^{-kt}$ + (1-a) $\exp^{-k_1 at}$	stem	0.992852	0.0012111	0.162235
		leave	0.990607	0.001029	0.099815
		root	0.994101	0.000647	0.038189
Henderson and Pabis	MR = a $\exp^{(-kt)}$	stem	0.989271	0.001093	0.143208
		leave	0.991422	0.000970	0.091155
		root	0.996255	0.000433	0.024240
Logarithmic	MR = a $\exp^{(-kt)}$ + c	stem	0.992922	0.000721	0.094471
		leave	0.993847	0.000696	0.065391
		root	0.996385	0.000418	0.023402

The color of fresh celery is shown in Table 2. The color values were expressed in term of L*, a* and b*. The L* refers to the brightness which was higher in celery roots than the other parts. For a* value, -a* is indicated the green direction and a* is the red direction. Therefore, the celery leaves show had high greenness while the celery roots trended to be redness. For b* value, b* is indicated the yellow direction which more yellowness in celery stem.

The effects of drying temperature on the discoloration of celery in all parts are presented in Table 3. There is no doubt that drying at 60 °C caused the higher discoloration which was agreed with the previous work of Arslan and Ozcan (2008). This may be the pigment degradation during drying process and browning reaction occurring, resulted in the colour changes (Negi and Roy, 2001; Sinnecker et al., 2005). For the L* which indicate the brightness, the results found that after drying the L* values decreased, showing that the dried samples were darker which was agreed with report of Maskan (2001). In this study, the dried samples from each drying temperature derived from difference drying time, the lower drying temperature was longer drying time to reach the equilibrium moisture content. However, the color changes were more affected by drying temperature than by drying time.

Table 2. The color values of fresh celery before drying.

Celery part	L*	a*	b*
Stems	48.98	-8.55	34.02
Leaves	48.03	-11.10	30.29
Roots	55.39	4.14	21.46

Table 3. Change of celery color in all parts after drying at different drying temperatures.

Drying temperature (°C)	Stems	Leaves	Roots
	ΔL*		
40	4.58 ± 0.03 [a]	4.76 ± 0.03 [a]	5.15 ± 0.02 [a]
50	4.79 ± 0.03 [b]	5.24 ± 0.12 [b]	6.66 ± 0.03 [b]
60	5.24 ± 0.06 [c]	8.85 ± 0.05 [c]	9.22 ± 0.06 [c]
	Δa*		
40	-3.00 ± 0.08 [a]	-2.98 ± 0.07 [a]	-2.76 ± 0.11 [a]
50	-5.09 ± 0.16 [b]	-3.12 ± 0.03 [b]	-2.79 ± 0.03 [a]
60	-6.86 ± 0.08 [c]	-3.98 ± 0.04 [c]	-3.62 ± 0.12 [b]
	Δb*		
40	-0.81 ± 0.08 [a]	5.13 ± 0.04 [b]	-3.01 ± 0.16 [a]
50	-0.86 ± 0.23 [a]	6.99 ± 0.14 [a]	-3.04 ± 0.04 [a]
60	-2.48 ± 0.58 [b]	7.01 ± 0.09 [a]	-3.50 ± 0.08 [b]

Means within a column each color value with the same letter are not significantly different ($p \leq 0.05$) by DMRT

Conclusions

The drying rate of celery leave, stem and root increased with the drying temperature and it was shown that the root part had the highest drying rate. The best performing empirical model to predict the drying behaviour of celery in three parts was the same of Logarithmic model. For the color assessment, in all parts of dried celery, the L* value decreased and a* value increased with the increasing of drying temperature except the b* value that increased in roots and stems part.

Acknowledgement

The authors would like to thanks Mr. Tounthong Janpratad and Mr. Weerachart Pimpo for their hard working. The financial support from Faculty of Engineering Mahasarakham University was appreciated.

Nomenclature

a, c,k, n	drying constants	MR	moisture ratio	T	temperature	°C
exp	exponential	N	number of observations	t	time	min
i	initial	R^2	coefficient of determination			
M	moisture content dry basis	SSE	sum of square error			

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