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# แบบจำลองการแตกและการร้าวของถั่วเหลืองภายใต้การอบแห้งด้วย NIR ร่วมกับฟลูอิไดซ์เบด
# Cracking and breakage models of soybean kernels under combined NIR and fluidized-bed drying

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## Abstract

The mathematical models of cracking and breakage of soybean kernels were investigated under combined near-infrared radiation (NIR) and fluidized-bed drying. In this study, the following drying parameters were set for investigation: near-infrared radiation powers of 4, 6 and 8 kW, air velocities of 3.3, 4.5 and 5.7 m/s, air temperature of 40°C, soybean bed depth of 6 cm with 20% dry basis initial moisture content of soybean kernels. The linear, quadratic, cubic, sigmoid and logistic models were tried on various cracking and breakage kernels. The results showed that the cracking and breakage of soybean kernels occurred only slightly (below 6%). The sigmoid model satisfactory described for the changes of both cracking and breakage of soybean kernels ($R^2 > 0.9817$, EF > 0.9825, RMSE < 0.10674 and chi-square < 0.01353).

**Keywords:** Near-infrared radiation, Soybean grains, Cracking, Breakage

## บทคัดย่อ

แบบจำลองทางคณิศาสตร์ของการแตกและการร้าวของเมล็ดถั่วเหลืองจะถูกตรวจสอบภายใต้การอบแห้งด้วยรังสีอินฟราเรดคลื่นสั้น (NIR) ร่วมกับฟลูอิไดซ์เบด ในการศึกษาครั้งนี้ ตัวแปรของการอบแห้งสำหรับการตรวจสอบคือ กำลังของการแผ่รังสีอินฟราเรดคลื่นสั้น 4, 6 และ 8 kW ความเร็วของอากาศ 3.3, 4.5 และ 5.7 m/s, อุณหภูมิอากาศอบแห้ง 40°C, ความสูงเบดของเมล็ดถั่วเหลือง 6 cm และความชื้นเริ่มต้นของเมล็ดถั่วเหลือง 20% dry basis แบบจำลอง linear, quadratic, cubic, sigmoid และ logistic ได้นำมาประยุกต์ใช้ในแบบจำลองของการแตกและการร้าว ผลการทดลองพบว่า การแตกและการร้าวของเมล็ดถั่วเหลืองเกิดขึ้นเพียงเล็กน้อย (ต่ำกว่า 6%) และแบบจำลอง Sigmoid สามารถอธิบายการเปลี่ยนแปลงการแตกและการร้าวของเมล็ดถั่วเหลืองได้เป็นที่น่าพอใจ ($R^2 > 0.9817$, EF > 0.9825, RMSE < 0.10674 และ chi-square < 0.01353)

**คำสำคัญ**: รังสีอินฟราเรดคลื่นสั้น เมล็ดถั่วเหลือง การร้าว การแตก

## Introduction

The soybean kernel is harvested usually at high moisture levels. High moisture content is one of the most important factors affecting the quality of soybean kernels during storage and subsequent handling. The moisture content level of soybean kernels at the time of harvest may be as high as 35% dry basis and this must be reduced to about 14% dry basis for the safety storage. Therefore, the drying process is necessary to prevent quality deterioration. The most common drying method for soybean kernels in Thailand and the world is convective drying, which provide high heat and mass transfer rate between the hot-air and the soybean kernels (Overhult et al., 1973; Osella et al., 1997; Barrozo et al., 1998; Soponronnarit et al., 2001). However, the convective drying method is tremendous loss of thermal energy in the convective drying; making it a less efficient process and the

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higher air temperature is a sensible factor impacting the quality of soybean kernels (Feng and Tang., 1998). In recent years, the infrared radiation was applied in the drying process (Sandu., 1986; Sakai and Hanzawa., 1994; Abe and Afzal., 1997; Afzal et al., 1999; Pan et al., 2008; Das et al., 2009), the infrared radiation impinges on the exposed material and penetrates into it and the energy of radiation converts into heat (Ginzburg, 1969). The advantages of infrared radiation technology in dehydrating foods includes a decreased in drying time, high energy efficiency, high quality finished products, uniform temperature in the product and reduced necessity for air flow across the product (Mongpreneet et al., 2002).

The mathematical modeling of drying characteristic and quality is necessary for the design process, to derive basic kinetic information of a system in order to describe the reaction rate as a function of experimental variables and, to predict changes in a particular food during drying (Van Boekel, 1996). Several researchers have developed mathematical models for infrared radiation drying systems (Dilip and Pankaj., 2004). However, the mathematical model for near-infrared radiation assisted cracking and breakage of soybean kernels could not be found in the literature. Therefore, the purpose of this present study was to investigate the suitable model for expressing the cracking and breakage of soybean kernels under combined NIR and fluidized-bed drying.

## Materials and methods

The combined NIR and fluidized bed dryer was used in this study. Its components of the dryer are mainly comprised of a drying chamber, 12 kW near-infrared radiators, 12 kW hot-air heaters and a backward curve centrifugal fan driven by 3 kW motor. Soybean kernels (Chiang Mai 60); at initial moisture content of 20% dry basis purchased from the Loei Field Crop Research Center in Loei province, Thailand. The drying conditions were set as follows; near-infrared radiation powers of 4, 6 and 8 kW, air velocities flowing through grain bed of 3.3, 4.5 and 5.7 m/s, drying air temperature of $40^{o}C$ and grain bed depth of 6 cm. The moisture content of soybean kernels during drying was determined by a hot-air oven at 103 $^{o}C$, 72 h (ASA 1990). The data of cracking and breakage were fitted with five different models as shown in Table 1.

Table 1 Mathematical models used for modeling of cracking (Cr) and breakage (Br) of soybean kernels in the drying process

| Model no. | Model names | Model equations |
|---|---|---|
| 1 | Linear | $Cr, Br = C + (kM)$ |
| 2 | Quadratic | $Cr, Br = C + (aM) + (bM^2)$ |
| 3 | Cubic | $Cr, Br = C + (aM) + (bM^2) + (dM^3)$ |
| 4 | Sigmoid | $Cr, Br = a / (1+\exp(-(M-x0)/b))$ |
| 5 | Logistic | $Cr, Br = a / (1 + (M/x_0)^{b})$ |

## Results and Discussions

The cracking and breakage of soybean kernels under combined NIR and fluidized-bed drying was inspected and the results are as shown in Fig. 1, for specific drying condition. The cracking and breakage was depending strongly on the final moisture content of soybean kernels; they slightly increased with the decrease of final moisture contents. Similarly, they were slightly increased with the increase of both near-infrared radiation power and air velocity. However, the cracking and breakage of soybean kernels under combined NIR and fluidized-bed drying were occurred negligibly (below 6%) when compared with individual hot-air fluidized-bed drying at the same level of moisture content.

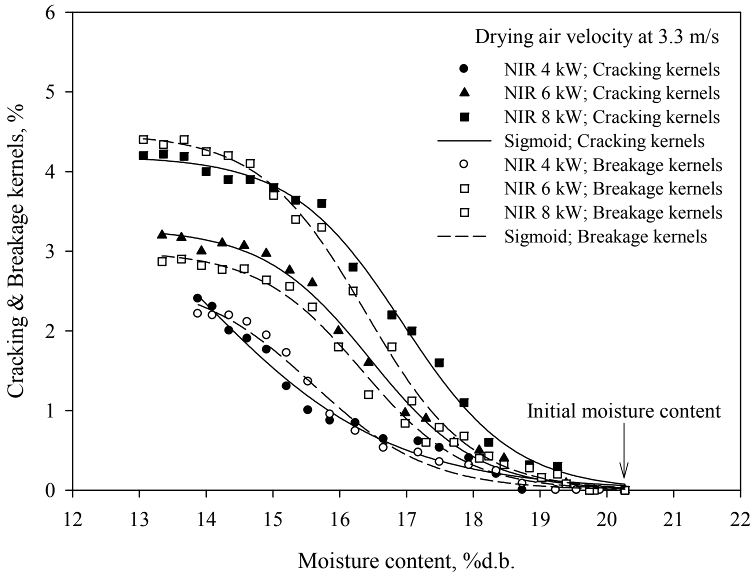

Figure 1 Crack and breakage of soybean kernels under combined NIR and fluidized-bed drying

Five different models (Table 1) were used to fit the experimental data of crack and breakage of soybean kernels. Results indicated that the sigmoid regression model has the highest fitting value having the coefficient of correlation of 0.9817, highest efficiency model 0.9825, lowest root mean square error 0.10674 and lowest chi-square 0.01353, of among all five regressions result. Therefore, the variations in the crack and breakage of soybean kernels during drying were adequately simulated by sigmoid model. The sigmoid model, constant values (a, b and $x_o$) was expressed in terms of near-infrared radiation power and air velocity as follows:

$$Cr, Br = a / (1+\exp(-(M-x_0)/b))$$

For cracking (Cr);

$$a = 23.19-4.658V-3.359P+0.289VP+0.322V^2+0.187P^2;\ R^2 = 0.9629 \quad (1)$$

$$b = -4.116+0.585V+0.538P-0.062VP-0.019V^2-0.016P^2;\ R^2 = 0.8362 \quad (2)$$

$$x_0 = -5.2+4.625V+3.339P-0.251VP-0.322V^2-0.154P^2;\ R^2 = 0.9648 \quad (3)$$

For breakage (Br);

$$a = 4.078+1.088V-1.873P+0.085VP-0.143V^2+0.176P^2;\ R^2 = 0.9890 \quad (4)$$

$$b = 1.966-1.146V-0.047P-0.014VP+0.125V^2+0.005P^2;\ R^2 = 0.7862 \quad (5)$$

$$x_0=16.7-1.866V+1.236P-0.091VP+0.237V^2-0.068P^2;\ R^2 = 0.8917 \quad (6)$$

## Summary

The present study has demonstrated that the cracking and breakage of soybean kernels was occurred negligibly under combined NIR and fluidized-bed drying. The sigmoid model was provided the satisfactory description for the changes of both cracking and breakage of soybean kernels ($R^2$ > 0.9817, EF > 0.9825, RMSE < 0.10674 and chi-square < 0.01353).

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