Foam-mat Drying of Mango cv. Chok Anan
การทําแห้งแบบโฟมของมะม่วงพันธุ์โชคอนันต์

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ABSTRACT
This study aimed to investigate the effect of concentration of carboxymethylcellulose (CMC) (0, 0.25, 0.5 and 1.0%) and whipping time (0, 10, 20 and 25 min) on mango foam properties. Effect of drying temperature on drying behavior of mango foam was also determined. It was found that incorporation of 0.5% CMC and whipping time of 25 min produced the foam with the lowest density ($p \leq 0.05$). Drying experiments showed that falling rate period was observed for mango foam dried at 60, 65 and 75°C. Drying rate and moisture diffusivity ($D_{eff}$) increased with increasing temperature. The activation energy of mango foam drying was found to be 22.22 kJ/kmol.

บทคัดย่อ
การศึกษานี้มีวัตถุประสงค์เพื่อตรวจสอบผลของความเข้มข้นของสารคาร์บอกซีเมทิลเซลลูโลส (CMC) (ร้อยละ 0, 0.25, 0.5 และร้อยละ 1.0) และเวลาในการตีปั่น (0, 10, 20 และ 25 นาที) ต่อสมบัติของโฟมจากเนื้อมะม่วง นอกจากนี้ยังศึกษารูปแบบของโฟมจากเนื้อมะม่วงที่ตีปั่นต่อพฤติกรรมการทําแห้งของโฟมนีโอเมะว่างด้วยจากการทดลองพบว่าการเติม CMC ลงในเนื้อมะม่วงปริมาณร้อยละ 0.5 และตีปั่น 25 นาทีจะทําให้เกิดโฟมที่มีความหนาแน่นต่ําสุดอย่างมีนัยสําคัญ ($p \leq 0.05$) การทําแห้งของโฟมที่ตีปั่นต่อพฤติกรรมการทําแห้งของโฟมนีโอเมะว่าง ช่วงการทําแห้งลดลง ค่าการแพร่ความชื้น (D_{eff}) ของเนื้อมะม่วงเพิ่มขึ้นเมื่ออุณหภูมิการทําแห้งเพิ่มขึ้น ค่าพลังงานกระตุ้นของการทําแห้งของเนื้อมะม่วงมีค่าเป็น 22.22 กิโลจูลต่อกิโลโมล

Key Words: Foam-mat drying, mango, moisture diffusivity

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Introduction

Chok Anan is one of the mango varieties of Thailand. It is mainly produced in the northern and northeastern parts of Thailand for domestic fresh market and small scale processing. It is appreciated for its light to bright yellow color and its sweet taste (Spreer et al., 2009). In contrast to most mango varieties, it has the ability to produce off-season flowering without chemical induction (Chintanawong et al., 2001). Thus, apart from the main harvest in May, two more harvests follow in June and August, generating additional income for farmers and reducing the labor peak at harvest (Spreer et al., 2009).

Normally, mango is a highly perishable tropical fruit with limited shelf-life and is susceptible to mechanical damage during post harvest handling and transportation. Therefore, the conversion of the fruit into powder could be useful not only to reduce post harvest loss but also to retain nutritional quality in the processed products (Rajkumar et al., 2007).

Mango powder produced from mango pulp can be used in many products such as pudding, bakery fillings. In addition it can be used as a flavoring ingredient in ice cream, yoghurt, mango fruit bar and mango toffee.

Foam-mat drying of food involves the incorporation of substantial volume of air or other inert gases with a presence of foaming agent into liquid or semi-solid foods to form stable foam. The foam thus formed is spread as a thin mat or sheet and dried in hot air stream until its desirable final moisture content is reached (Labelle, 1984). The dried product is then converted into power. Because of a very high surface area of foam exposed to the drying air, the rate of water removal during drying is accelerated as well as the drying time is shortened (Labelle, 1984). The dehydrated powder with porous structure obtained from this process exhibits a good reconstitution property (Labelle, 1984).

The main advantages of foam-mat drying technique, when compared to other drying methods such as drum drying and spray drying, are lower drying temperatures and shorter drying times. In addition foam-mat drying process is a relative simple and inexpensive process (Karim and Wai, 1999) therefore it can be applied to produce fruit powder with relatively high quality.

Foam-mat drying of starfruit by foaming with different concentrations of methocel and drying as a 5-mm thick layer in a mini kiln smoker at temperatures ranging from 70 to 90°C with an air flow rate of 0.12 m/s showed that obvious color and flavor changes were observed in the product dried at 90°C (Karim and Wai, 1999)

Rajkumar et al. (2007) concluded that Alphonso mango foam prepared by adding 10.0% egg albumin and 0.5% methylcellulose and then dried at 60°C with 1 mm thickness provided the dried product with high qualities. Akintoye and Oguntunde (1991) reported that the suitable condition of drying soymilk foam was 65°C for 90 min. Drying foamed soymilk at this condition occurred in a falling rate period and the drying rate depended on the foam density. Falade et al. (2003) reported that cowpea foam stabilized with 12.5% glyceryl monostearate and dried at 60°C for 48 min gave out the dried product with high quality in terms of color values and solubility.
Foaming and drying conditions of mango from different parts of the world have been reported. However, no work has been done involving foaming and drying characteristics of Thai mango cv.Chok Anan. This present paper aimed to investigate the foaming condition and drying behavior of foamed mango pulp cv.Chok Anan.

Materials and methods

Material preparation

Mango cv. Chok Anan was purchased from local market at Khon Kaen province, Thailand. Fresh, fully ripened mangoes with uniform color were selected and washed with tapped water. The mangoes were then peeled by very sharp knives. The mango puree was prepared by blending flesh portion of mango pulp in a blender with maximum speed for 2 min and then used for foaming and drying studies.

Foaming experiment

Foaming agent, carboxymethylcellulose (CMC) was incorporated into mango puree at 0.0%, 0.25%, 0.50% and 1.0% (on a wet puree basis). The mixture of mango puree and foaming agent was whipped in a Kenwood mixer (KitchenAid Heavy duty 5k5ss, USA.) at a maximum speed for 0, 10, 20 and 25 min. The properties of foam such as foam density, foam expansion and foam stability were measured for each experimental condition.

Foam density was determined by measuring the mass (m) of a fixed volume (V) of the foam and expressed as g/cm$^3$ as recommended by Thuwapanichhayanan et al. (2008).

Foam density = $\frac{m}{V}$  \hspace{1cm} (1)

The determination of foam density was done in duplicate.

Foam expansion was determined by comparing the volume of puree and volume of corresponding foamed puree according to the method described by Rajkumar et al. (2007). Foam expansion was calculated using the following relationship:

Foam expansion = $\left[\frac{V_i - V_0}{V_0}\right] \times 100$  \hspace{1cm} (2)

where $V_0$ is the initial volume of puree and $V_i$ is the volume of foam, m$^3$.

The 4x4 Factorial in RCBD was used in this experiment. Statistical analysis of the experimental data was carried out with SPSS for Windows.

Foam-mat drying experiment

The homogeneous foamed mango puree was evenly spread on the aluminum tray of size (18.7x27.5x0.10cm) at a foam thickness of 1 mm. The trays with foamed sample were put into the tray dryer (Arnfield, England) and then dried at 60, 65 and 75 °C. The weight loss during drying at each temperature was monitored every 5 min using data logger (Datataker DT800, England).

Fick’s second law of diffusion was used to determine the moisture diffusion during drying of foamed mango puree spread in the form of a thin slab. The equation is:

$$\frac{M - M_e}{M_o - M_e} = \frac{8}{\pi^2} \left( \frac{D_{eff} \pi^2 t}{4L^2} \right)$$  \hspace{1cm} (3)

where $M$, $M_e$ and $M_o$ are moisture content at any time (%db), equilibrium moisture content (%db) and initial moisture content (%db), respectively. $D_{eff}$ is moisture diffusion coefficient.
diffusivity (m$^2$/s) and $L$ is the thickness of the foam (m).

To obtain the moisture diffusivity value, experimental drying data at each temperature was fitted with Eq. (3) using non linear regression technique. In the fitting Process, equilibrium moisture content ($M_e$) was assumed to be zero.

Moisture diffusivity can be related to temperature by Arrhenius expression like (Thuwapanichhayanan et al., 2008):

$$D = D_o \exp \left( \frac{-E_a}{RT_{abs}} \right)$$

where, $D_o$ is the constant value (m$^2$/s), $E_a$ is the activation energy (kJ/kmol), $R$ is the universal gas constant (8.314 kJ/kmol K) and $T_{abs}$ is absolute drying temperature (K).

### Results and discussion

#### Foaming properties of mango puree

Effect of whipping time on foam density and foam expansion at different concentrations of CMC is shown in Table 1.

<table>
<thead>
<tr>
<th>Level of CMC (%)</th>
<th>Whipping time (min)</th>
<th>Foam property</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Density (g/ml)</td>
</tr>
<tr>
<td>0.0</td>
<td>0</td>
<td>1.018±0.001$^{ab}$</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1.014±0.002$^b$</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>1.013±0.003$^b$</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>1.015±0.001$^b$</td>
</tr>
<tr>
<td>0.25</td>
<td>0</td>
<td>1.017±0.002$^{ab}$</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.898±0.003$^c$</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.789±0.003$^d$</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.725±0.001$^e$</td>
</tr>
<tr>
<td>0.50</td>
<td>0</td>
<td>1.024±0.008$^e$</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.508±0.002$^g$</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.454±0.001$^h$</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.335±0.009$^i$</td>
</tr>
<tr>
<td>1.0</td>
<td>0</td>
<td>1.010±0.002$^d$</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.591±0.002$^j$</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.363±0.003$^i$</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.421±0.004$^f$</td>
</tr>
</tbody>
</table>

Mean within the same column with different letters are significantly different ($p$$\leq$0.05).

As seen in Table 1, a rise in amount of CMC from 0% to 0.50% at a given whipping time (except 0 min) resulted in a significant decrease ($p$$\leq$0.05) of foam density but a significant increase in foam expansion. Higher expansion indicates that more air was trapped in the foam and this gave rise to lower foam density. Foam expansion increased drastically after whipping mango puree with
0.5% CMC for 25 min (Table 1). This indicates that 0.5% (w/w) of CMC and 25 min of whipping time are required to form the stable foam in mango puree. However, increasing the CMC concentration further beyond 0.5% resulted in a decrease of foam expansion. This is because increasing CMC above 0.5% increases the viscosity of the mixture, possibly exceeding the limiting viscosity at which maximum volume of air can be incorporated; this results in reduction of the foam expansion. Karim and Wai (1999) reported that addition of CMC above 0.4% in star fruit puree reduced the foam expansion. They explained that high viscosity liquid prevented the trapping of air during whipping.

Based on these results, it was decided to conduct the foaming study with whipping time of 25 min and 0.5% (w/w) of CMC.

**Drying characteristics of foamed mango puree**

Effect of drying temperature on the variation of moisture ratio of foam mango puree during drying is shown in Fig. 1.

![Figure 1](image)

**Figure 1** Relationship between moisture ratio and drying time of foamed mango puree at different temperatures
It is evident from Fig. 1 that drying at a higher temperature can reduce the drying time. At 75°C, the moisture ratio of the mango foam was reduced down to 0.01 in 40 min, i.e. 10 min faster than at 60°C. This is because the rate of water removal from the foam at 75°C is faster than at 60°C. As seen in Fig. 2 drying rate of mango foam at three different temperatures showed the presence of a heat up period at the first 5 min of drying and then followed by the falling rate period. At the early state of drying, moisture content of the foam is still high, thus by using temperature between 60°C and 75°C the drying rate can be increased. After the surface of the foam dries out, the rate of water movement from the interior to the surface of the foam falls below the rate at which water evaporates to the surrounding air and this is the sign of falling rate period (Fellows, 2000). The drying rate increased with increase in the temperature of the drying air and the highest values of drying rate were obtained at drying air temperature of 75°C at the first 20 min (Fig. 2). After 20 min, drying rates at 75 and 65°C was lower than that at 60°C. Generally, drying rate decreases continuously with decreasing moisture content or improving drying time (Yaldiz and Ertekin, 2001). The moisture removal inside the foam at 75°C is higher and faster than the others at first 20 min and then it becomes lower than the others. Since the migration to surface of moisture and evaporation rate from surface to air decrease with decrease of the moisture in the foam, the drying rate clearly decrease.

The results of this work were in agreement with the work of Karim and Wai (1999) and Thuapanichhayanan et al. (2008) who reported that a heat up period and falling rate period were found during drying of star fruit foam and banana foam, respectively.
Table 2 Moisture diffusivity of mango foam dried at different temperatures.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>$D_{eff} \times 10^9 (m^2/s)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>4.27 ($r^2 = 0.903$)</td>
</tr>
<tr>
<td>65</td>
<td>5.13 ($r^2 = 0.909$)</td>
</tr>
<tr>
<td>75</td>
<td>6.18 ($r^2 = 0.923$)</td>
</tr>
</tbody>
</table>

The moisture diffusivity values of mango foam at different drying temperatures are shown in Table 2. Moisture diffusivity ranged from $4.27 \times 10^{-9} m^2/s$ at 60°C to $6.18 \times 10^{-9} m^2/s$ at 75°C. It can be seen that $D_{eff}$ increased with increasing temperature. Thuwapanichhayanan et al. (2008) reported that the moisture diffusivity of banana foam during drying increased from $2.34 \times 10^{-9} m^2/s$ to $3.60 \times 10^{-9} m^2/s$ when drying temperature increased from 60°C to 80°C.

The relationship between $D_{eff}$ and absolute temperature was expressed as:

$$D = 13473.168 \exp\left(-\frac{22.22}{RT}\right) (r^2 = 0.973)$$

The activation energy for mango foam drying in this study was 22.22 kJ/kmol. Thuwapanichhayanan et al. (2008) reported that the activation energy of banana foam dried at temperature ranging from 60°C to 80°C was 21.08 kJ/kmol.

Conclusion

Addition of carboxymethylcellulose at concentration of 0.5% and whipping time of 25 min resulted in the mango foam with the lowest density and the highest expansion. Drying of mango foams mostly occurred in the falling rate period with higher drying rate at higher drying temperature. Moisture diffusivity values increased from $4.27 \times 10^{-9} m^2/s$ to $6.18 \times 10^{-9} m^2/s$ when drying temperature increased from 60°C to 75°C. The activation energy of mango foam during drying determined using Arrhenius type equation was 22.22 kJ/kmol.

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References


Chintanawong, S., Tidiprasert, W., Chaichakan, M., See Angoonsathian, N. and Sriphotha, D. 2001. Plant Germplasm Data base for Mango. Department of Agriculture of Thailand,


