

THE EFFECT OF DRYING WITH CONTROLLING RELATIVE HUMIDITY OF DRYING AIR ON THE COLOR AND TEXTURE OF MANGO SHEET PRODUCTS

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Abstract:

Mango sheet is one of the traditional mango products that is produced for preservation and market-value addition purposes. Currently, the factory encounters the problem about the long drying time requirement of this product. Therefore, this research aimed to increase the efficiency of drying mango sheets by proposing the hot air drying method that controlled the relative humidity (RH) of drying air. In this study, three drying schemes namely conventional hot air drying (60 °C), single-stage drying (60 °C/15% RH), and two-stage drying (80 °C for 1 h 5 min in the 1st stage and then adjusted to 60 °C/15% RH in the 2nd stage) were applied in the mango sheet drying until reaching the moisture content of approximately 16.8% wet basis (w.b.) which is comparable to the commercial product. The color and textural properties, consisting of firmness and adhesiveness of mango sheets dried by these methods were determined and compared with those of the commercial product. It appeared that all of the drying schemes required shorter drying time than that of the current practice in the factory, especially when the relative humidity of drying air was controlled. The color intensity of the sample dried by conventional hot air drying product was the lowest, followed by the two-stage, and single-stage drying respectively whereas all the color values of commercial product was greater than its counterparts. In addition, the firmness and adhesiveness of conventionally-dried samples were higher than the two-stage dried sample, commercial product, and single-stage dried mango sheets respectively. This research proved that the drying process that applied the relative humidity control which is the similar concept to the heat pump dryer could noticeably shorten the drying time compared to the general hot air drying methods while its product quality was not much different from the commercial product.

Keywords: Drying; Heat pump; Hot air drying; Mango sheet; Relative humidity control

Introduction

Mango is one of the most important economic fruit in Thailand due to its large production area of more than 300,000 hectares. It has captivating color, individual flavor, and abundant nutritional value (Matheyambath *et al.*, 2016; Matulaprungsan *et al.*, 2019). In addition, it can grow in many regions of Thailand because of the suitable geography and atmosphere (Matheyambath *et al.*, 2016); however, mango is a highly perishable fruit because it has a short shelf life and thin peel which is susceptibility to physical injury that facilitate microorganism growth (Moalemiyan *et al.*, 2012). So, the processing of fresh mango into mango sheets is a practical alternative to extend the mango shelf life, increase market value, and diminish the logistic cost (Chou & Chua, 2001). Mango sheet is a traditional snack made by drying a thin layer of mango puree. Its popularity causes by its sweetness taste, chewy texture and long shelf life under room temperature (Diamante *et al.*, 2014). Sun drying is the traditional method for

drying mango sheet; however, the disadvantages of this method are its long drying period, uncontrollable drying condition, and unhygienic process. So far, the food industry has developed mechanical dryers to overcome these problems such as hot air dryer (Maskan *et al.*, 2002; Diamante *et al.*, 2014). Although hot air drying method requires a shorter time than sun drying and is more hygienic, most hot air dryers are still open systems. Moreover, the hot air in the drying chamber frequently contains high moisture as a result of moisture transfer from food (Wang *et al.*, 2011). As a consequence, if this hot air was totally recycled without the mixing of the fresh air, the drying efficiency would decrease.

Heat pump dryer (HPD) is a novel dryer that has the potential to be applied in the mango sheet drying. The benefit of heat pump drying is its closed-loop system; therefore, the process is more hygienic compared to those of the open system. Moreover, its capability to recycle heat back to the drying process leads to the high energy efficiency and subsequently energy cost saving (Kivevele & Huan, 2014). Duan *et al.* (2019) investigated the thermal characteristic of hawthorn cakes which were dried by a HPD in comparison with that of the conventional hot air dryer (HAD). They found that air humidity in HPD was lower than HAD around a half; consequently, HPD has a greater drying rate and energy saving than HAD. Pal *et al.* (2008) claimed that the lower relative humidity of drying air leads to the increase of driving force of moisture transfer from the surface of food material to the air.

The key objective of the present work was to increase the efficiency of drying mango sheets by proposing the hot air drying method that controlled the relative humidity of drying air which imitated the occurrence in the heat pump dryer. The outcome of this research would be beneficial to the mango sheet producers who have the problem about the long drying time requirement and high energy consumption in the manufacturing process of mango sheet.

Materials and Methods

Sample Preparation

Mango puree and commercial mango sheet products were supplied by Woraporn Fruit Processing Co., Ltd., Chachoengsao, Thailand. Mango puree was spread into the plastic mold plate placed on the aluminum tray. The diameter of each hole of the plastic mold plate was 47 mm whereas its depth was 4 mm. The aluminum trays containing mango puree were put into the dryer in order to process the mango puree to be mango sheets.

Drying Experiments

The commercial mango sheet product was manufactured using two-stage drying methods. First, the tunnel dryer was applied at 65 °C for 4-5 h. After that, the heat pump dryer was used for about 48 h by setting the drying air temperature at 60 °C and 10% RH. However, the actual drying air condition in the heat pump drying chamber was not same as the setting values due to the incompatibility between the dryer capacity and the size of drying chamber. The temperature was much lower whereas the relative humidity was considerably higher than the set values.

In the present study, mango puree samples were dried using three different drying schemes consisting of (1) conventional hot air drying at temperature of 60 °C (Gujral & Brar, 2007) without RH control of drying air (average RH \approx 48%), (2) single-stage drying at 60 °C with RH control at 15%, and (3) two-stage drying applying temperature at 80 °C for 1 h 5 min in the 1st stage and then adjusted to 60 °C with RH control at 15% in the 2nd stage. The drying air velocity was in the range of 1.0-1.5 m/s. All the samples were dried until reaching the

moisture content of approximately 16.8% w.b. which is analogous to the moisture content of commercial product. The drying without RH control was carried out in the hot air oven (MEMMERT, UF 55, Germany) whereas a constant climate chamber (BINDER, KBF-240, Germany) was applied for the drying with RH control. The hot air drying with the RH control was conducted to imitate the operation of the heat pump dryer. After drying, the mango sheets were removed from the aluminum trays, filled in the aluminum foil bags, and kept at room temperature before quality determination. The drying experiments were conducted in triplicate for each drying scheme.

Color Measurement

Color of the mango sheets were measured using a Hunter Lab Colorimeter (Hunter Lab, Model UltraScan PRO, USA) using the L, a, b scale, where L represents lightness ($0 \leq L \leq 100$), while a (+), a (-), b (+) and b (-) represent redness, greenness, yellowness, and blueness, respectively. The colorimeter was calibrated with a black card device using illuminant D65 and the 10° standard observer. (Azeredo *et al.*, 2006). The measurement was carried out in triplicate for the sample collected from each drying run.

Textural Property Measurement

The firmness and adhesiveness values of mango sheets were analyzed applying a texture analyzer (Stable Micro Systems, Model TA.XT.plus, UK). The method was modified from Suna & Karabacak (2019). The samples were stacked on two pieces. A light knife blade probe was used to compress the top mango sheet to 40% deformation at a pre-test speed of 1 mm/s, test speed of 2 mm/s, and post-test speed of 2 mm/s. The measurement was conducted in three replications for the sample collected from each drying run.

Statistical Analysis

The software package SPSS (ver. 16.0) was used for the statistical analysis. The significant differences between the mean values of all the experimental data were analyzed by one-way analysis of variance (ANOVA) with Duncan's New Multiple Range Test at a confidence level of 95% ($p < 0.05$).

Results and Discussion

Drying Characteristics

Drying kinetics of mango sheets during drying processes are illustrated in Figure 1. It appeared that at the beginning of the drying process, heat from drying air was transferred to mango puree, which had high initial moisture content; therefore, free moisture on the sample surface was rapidly transferred to the drying air. After that, the drying rates were lower because they relied on the moisture diffusion from inside to the surface of mango sheets (Traub, 2002; Argyropoulos *et al.*, 2011). The required periods for drying mango puree samples to the final moisture content of about 16.8% w.b. were 14, 11, and 9 h in cases of applying the conventional hot air drying, single-stage, and two-stage schemes respectively. It is obvious that all of these drying experimental conditions spent shorter drying time than the current drying process of the commercial product applied in the factory. This should be due to the better drying condition control. The conventional hot air drying scheme that applied drying air temperature at 60 °C

without RH control (average RH \approx 48%) consumed apparently longer drying time than the single-stage and two-stage drying processes which combined relative humidity control because the higher relative humidity of the drying air decreased the moisture gradient between the sample surface and the drying air resulting in the decline drying rate and moisture diffusivity (Ju *et al.*, 2016). For the two-stage drying method, the mango sheets were dried at 80 °C in the first stage for 1 h 5 min leading to the moisture content reduction to approximately a half way between the initial moisture content and the required final moisture content. Although the first drying stage did not apply the relative humidity control of drying air, the drying rate was greater than its counterparts because the drying temperature of 80 °C provided the higher driving force for moisture transfer than that of 60 °C. Moreover, the drying air that was heated to the temperature of 80 °C would commonly have low relative humidity. Pal *et al.* (2008), Garavand *et al.* (2011), and Ju *et al.* (2016) claimed that the higher drying air temperature results in a highly thermal gradient between the sample and the drying air; hence, it causes a higher heat and moisture transfers than the lower drying temperature. In the second drying stage, the drying air temperature was decreased to 60 °C while the relative humidity control was applied in order to diminish the adverse effect of high temperature on the product quality and to accelerate the drying process. Therefore, the two-stage drying scheme spent the shortest drying time among all drying schemes applied in the present work. Azeredo *et al.* (2006) pointed out that high drying temperature could cause the reduction of mango sheet product quality such as darker color, harder texture and case hardening. That is the reason for the decrease of drying temperature to 60 °C when the moisture content of mango sheets declined to half way after the first stage drying in this study.

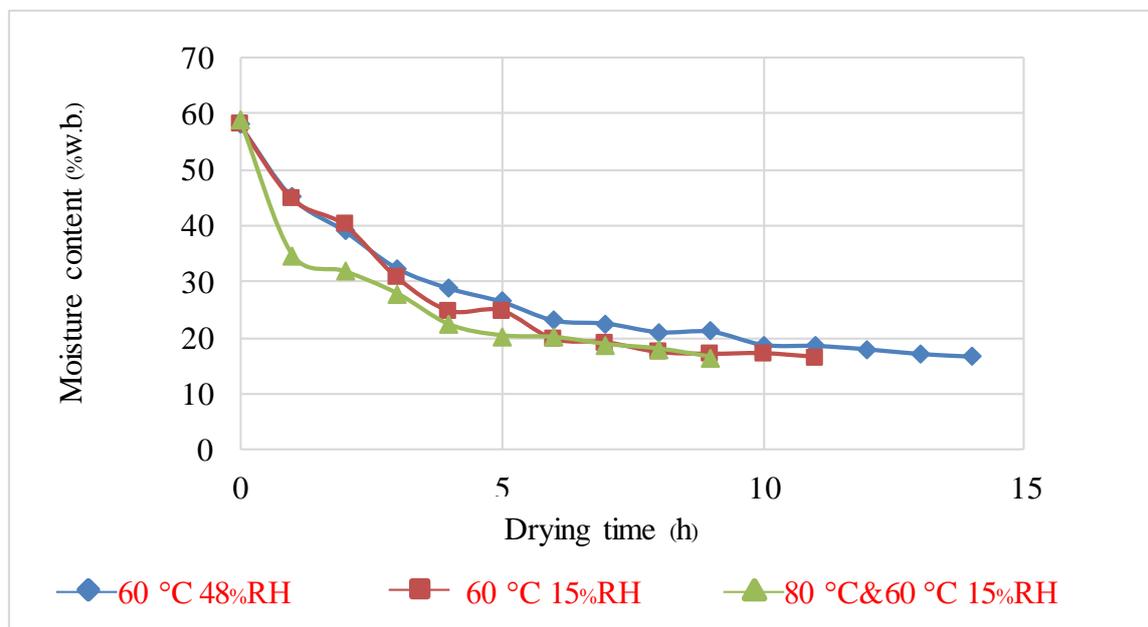


Figure 1: The drying characteristics of mango sheets in all drying conditions.

Color

The L, a, b values of mango sheets which were dried in the present work are shown in Table 1 and compared with the commercial product. Color values of the commercial product were the highest in every parameter followed by single-stage, two-stage, and conventional drying products, respectively. A lower L value implied that these samples are darker than the others.

Maillard reaction is a non-enzymatic browning reaction that occurred during the drying process. It generated the appearance of brown color on the food products whereas the brown color would be more intense when raising the drying temperature and drying time (Argyropoulos *et al.*, 2011). Due to the long drying time in the conventional hot air drying process, the Maillard browning reaction would occur in more extent and result in the lowest values of color lightness. It appeared that the mango sheet sample obtained from the two-stage drying scheme had significantly lower lightness than that of the single-stage drying although its drying time was shorter. It is because the higher drying temperature (80 °C) was applied in the first drying stage while the single stage drying scheme used a lower temperature (60 °C) of drying air throughout its drying process. Moreover, it appeared that the lightness value of the commercial product was the highest among all samples. It should be due to the fact that the commercial mango sheet product was dried at 65 °C for 4-5 h in the first stage and then it was dried by a heat pump dryer for around 48 h at lower drying temperature than 60 °C in the later stage. The photographs of all mango sheets samples are presented in Figure 2.

Table 1: Color values of mango sheets that were dried by different conditions.

Sample	L	a	b
Commercial product	70.63 ± 0.74 ^a	13.61 ± 0.57 ^a	44.93 ± 0.51 ^a
Conventional hot air drying (60 °C, 48% RH)	59.72 ± 0.63 ^d	12.67 ± 0.61 ^b	38.24 ± 0.43 ^d
Single-stage drying (60 °C, 15% RH)	63.52 ± 1.30 ^b	13.10 ± 0.93 ^b	40.80 ± 0.74 ^b
Two-stage drying (80 °C → 60 °C, 15% RH)	62.58 ± 0.50 ^c	12.46 ± 0.45 ^c	40.04 ± 0.36 ^c

Superscript with different letters a, b, c, and d in the same column show significantly different ($p < 0.05$).

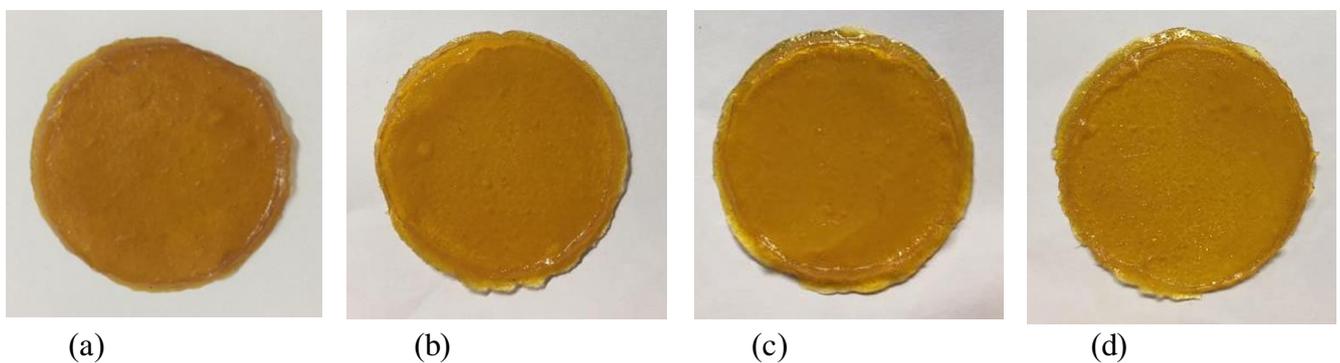


Figure 2: Photographs of mango sheet samples after drying; (a) Commercial product; (b) Conventional hot air drying; (c) Single-stage drying; (d) Two-stage drying.

Textural Property

The firmness and adhesiveness values of mango sheet samples are indicated in Table 2. It appeared that these values were significantly different among samples. The conventional hot air drying method provided the dried mango sheets that had the highest value of firmness and adhesiveness. It might be caused by the higher relative humidity of drying air during the

conventional hot air drying and subsequently the longest drying time compared to the single-stage and two-stage drying schemes. The longest drying time resulted in the non-uniformity of moisture distribution inside the samples. Although the mango sheet samples collected from all drying conditions had similar moisture content of around 16.8% w.b., they were likely to have dissimilar moisture distribution within the samples. For the sample dried by the conventional hot air drying method, their surface would have less moisture than the inside region of mango sheet sample due to its long drying time exposure. As a consequence, the sample surface would be denser and harder leading to the greater hardness and adhesiveness when measured. The firmness value of commercial mango sheet product was insignificantly different from that of the sample obtained from the two-stage drying while their adhesiveness were not much different because both drying methods applied two-stage drying concept which use higher drying temperature in the first stage and lower temperature in the second stage leading to the similar pattern of moisture distribution within the samples and subsequently comparable textural characteristics. It appeared that the mango sheets dried by the single-stage drying scheme at 60 °C/15% RH had the lowest firmness and adhesiveness. It might be due to its mild drying condition along the whole drying process and its shorter drying time than the conventional hot air drying method.

Table 2: Textural properties of mango sheet samples.

Sample	Firmness (kgf)	Adhesiveness (kg.sec)
Commercial product	3.82 ± 0.13 ^b	1.23 ± 0.10 ^c
Conventional hot air drying (60 °C, 48% RH)	4.77 ± 0.19 ^a	1.77 ± 0.13 ^a
Single-stage drying (60 °C, 15% RH)	2.92 ± 0.11 ^c	1.09 ± 0.18 ^d
Two-stage drying (80 °C → 60 °C, 15% RH)	3.83 ± 0.16 ^b	1.50 ± 0.16 ^b

Superscript with different letters a, b, c, and d in the same column show significantly different ($p < 0.05$).

Conclusion

The drying characteristics of mango sheets revealed that at the beginning of the drying process, the drying rate was high whereas it decreased along the drying period. The required periods for drying mango sheets to the final moisture content of around 16.8% w.b. were 14, 11, and 9 h in cases of applying the conventional hot air drying, single-stage, and two-stage schemes respectively which were much shorter than the current drying practice of the factory. The relative humidity control obviously resulted in the higher drying rate and consequently shorter drying time. For the two-stage drying method, the first stage drying at 80 °C for 1 h 5 min could reduce the moisture content of mango sheets to approximately a half way between the initial moisture content and the required final moisture content. The color values of commercial product were the highest in every parameter followed by single-stage, two-stage, and conventional drying products, respectively. Maillard reaction was expected to be a major cause of product color intensity. The long drying time in the conventional hot air drying process was speculated to result in the lowest values of color lightness. The lightness value of the commercial product was the highest among all samples. The firmness and adhesiveness values of mango sheet samples were significantly different among samples. The dissimilar moisture distribution within the mango sheets should be the reason for these textural property results.

The present work proved that the drying process that applied the relative humidity control which is similar to the occurrence in the heat pump dryer could obviously shorten the drying time compared to the drying without relative humidity control whereas the product quality was not much different from the commercial product.

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