XVII[th] World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

DRYER EVALUATION TO OPTIMIZE SMALL-SCALE LITCHI PROCESSING IN NORTHERN THAILAND

M. PRECOPPE[1], M. NAGLE[1], S. JANJAI[2], B. MAHAYOTHEE[2], J. MÜLLER[1]

[1] M. PRECOPPE, Department of Agricultural Engineering, University of Hohenheim, Garbenstraße 9, 70593 Stuttgart, Germany, marcelo.precoppe@uni-hohenheim.de.
[1] M. NAGLE, naglem@uni-hohenheim.de.
[1] J. MÜLLER, joachim.mueller@uni-hohenheim.de.
[2] S. JANJAI, Department of Physics, Silpakorn University, 73000 Nakhon Pathom, Thailand, serm@su.ac.th.
[2] B. MAHAYOTHEE, Department of Food Technology, busarakornm@yahoo.com.

CSBE100446 – Presented at Section VI: Postharvest Technology, Food and Process Engineering Conference

ABSTRACT In Thailand, litchis are produced primarily by smallholders in northern mountainous areas of the country. Currently, the profitability of this crop is jeopardized by unstable farmgate prices and insufficient access to markets. Local production of dried litchis by farmer cooperatives is a promising solution, yet existing drying technology for small-scale food processing yields products with heterogeneous quality and it has low energy performance. Aiming to develop energy-saving technology for producing high-quality dried fruits at an affordable cost, a locally available batch dryer used for litchi was evaluated at a farmer's cooperative. Non-uniform temperature distribution in the drying chamber was identified, resulting in fruits with heterogeneous moisture content, water activity and color. Each batch yielded approximately 15 kg of dried litchi and required about 15 kg of fuel. Specific thermal energy consumption of the dryer was 10.3 MJ per kilogram of evaporated water. Analysis of instantaneous indices, calculated to evaluate energy performance, demonstrated that the main heat loss was via exhaust air and that increasing the dryer's recirculation ratio or reducing the airflow rate could decrease this loss. Installing a frequency-converter to control the speed of the blower would allow an adjustable airflow rate and thus, the gradual reduction of airflow over the drying process. Convective heat loss through the dryer's walls was also high, which might be reduced by insulation. Overall, it is believed that the proposed modifications would produce significant improvements in dryer performance.

Keywords: Lychee, Air drying, Drying kinetics, Performance, Optimization.

INTRODUCTION Litchi (*Litchi chinensis* Sonn.) is an evergreen tree of the *Sapindaceae* family that is indigenous to the subtropics of southern China (Tindall, 1994). Litchi has a high commercial value due to its white, translucent aril and attractive red skin (Holcroft and Mitcham, 1996). About 95% of litchi production is located in Southeast Asia (Huang et al., 2005). For the Thai economy, litchis are among the fruit crops which have significant importance (Subhadrabandhu and Yapwattanaphun, 2001). About 80% of the litchi production area in Thailand is concentrated in the northern provinces (Anupunt and Sukhvibul, 2005). The majority of growers are smallholders (Subhadrabandhu, 1992). During the last 15 years, these farmers have experienced a reduction in profitability due to unstable farmgate prices and insufficient access to markets. As consequence, litchi orchards have been substituted by seasonal field crops, creating concerns about increased erosion, pesticide use and water demands (Schreinemachers et al., 2008). Litchi drying is an upgrading strategy that can decouple producer from the unstable fresh market and eliminate the middle man from the value chain (Boeer and Schipmann, 2008). Drying is the oldest litchi processing method (Chen and Huang, 2001). However, in Northern Thailand, drying technology is still in the early stages of development. A wide variety of convection dryers are used, but in general producers face difficulties in achieving uniform batches with the desired product properties (Precoppe et al., 2008).

The energy performance of drying equipment is often described by indices, such as evaporation rate, energy requirement and specific heat consumption. Such calculations elucidate the energy performance and are useful when comparing different dryers, but give no idea about energy utilization changes during the drying process and, therefore, have limited application on guiding design optimization (Kudra, 2004; Men'shutina et al., 2005). In contrast, instantaneous indices, calculated from time-distributed parameters, take into account temporal variations and can guide possible modification (Kudra, 2004; Strumiłło et al., 2007). With the aim to improve locally-available drying equipment for producing high-quality dried fruits at an affordable cost, the performance of a batch dryer used for litchi by a farmers' cooperative in Thailand was studied. Performance indices were calculated and the plotted against time. The analysis of those time-based indices was used to devise possible modifications the dryer.

MATERIAL AND METHODS

Drying procedure and measurements Four trials were conducted at a farmer cooperative located at the village of Mae Sa Noi in Chiang Mai province, Thailand. A locally-available convection batch dryer was used. This direct heated dryer was 1.75 m tall, 1.22 m wide and 1.22 m deep and the walls were made of 1.5 mm steel sheet metal. Seventeen squared trays sized 0.63 m² each, with metal sides and metallic mesh at the base, were stacked 9 cm apart in a tray rack. The tray rack was mounted on a carrousel and turned on its vertical axis making the trays rotate at 6 rpm. The system was powered by a 0.990 kW electric motor. The temperature of the air in the drying chamber was maintained by a thermostatically operated on-off control of a burner. The burner was fuelled by liquefied petroleum gas (LPG). Ambient air passed through the burner at a flow rate of 62.7 g s^{-1}. From the burner to the chamber, air flowed through a 4 m long air duct adjacent to the dryer. In this duct, the heated air mixed with part of the exhaust air produced a total flow of 112.5 g s^{-1}. Air was induced by radial blade blower powered by a second 0.990 kW electric motor. At the end of the duct, air entered the drying chamber through two longitudinal openings running the height of the chamber at the near right-hand corner of the dryer.

The trials followed the usual drying operation of the facility, where high grade ripe litchis (var. "Hong-Huay") grown in the surrounding Mae Sa watershed, were used. Fruits were harvested two days before starting the trial and kept at room temperature. The fruits were punched at the stem for deseeding and peeled by hand. Peeled fruits were, then, immersed in a 0.03% (w/v) citric acid ($C_6H_8O_7$) solution followed by a 0.05% (w/v) potassium metabisulphite ($K_2O_5S_2$) solution for 7 min at room temperature. After that, the fruits were placed on the trays in a single layer at a loading density of 11.44 ± 1.68 kg m^{-2}. The initial moisture content of the sample varied between 85 and 88% wet basis (w.b.). The drying process followed a stepwise temperature regime: the first step lasted for two hours at a target air temperature of 70 °C, the second step lasted six hours at 65 °C and the third step, at 60 °C, lasted until the fruit was dried to the desired moisture content. For estimating the product moisture content, the facility operator touched the fruits. To improve uniformity of the final product, trays were removed at various times during the last step according to the fruits' drying stage. Air velocity was kept constant. Average absolute humidity (x_d) of drying air was 24 ± 8 g kg^{-1}. Duration of the test period was 794 to 994 minutes.

Drying air temperature and relative humidity were recorded with 27 autonomous miniature thermometer-hygrometer data logger (TRH-logger) (Meilhaus Electronic, SugarCube Clima, Puchheim, Germany) placed over the dryer trays. Temperature and relative humidity of the ambient air were also recorded with a TRH-logger. Exhaust air temperature, relative humidity and velocity were measured by placing a TRH-logger and a vane probe anemometer (Schiltknecht, MiniAir 6 Mini, Gossau, Switzerland) at the dryer outlet. For calculation of air flow, a 350 mm long 5" plastic tube was placed as air duct at the dryer air outlet. The same anemometer was used to measure the velocity of the heated air entering the drying chamber, placing it near the chamber air inlet together with a humidity-temperature probe (HygroClip®) (Rotronic, SC05, Bassersdorf, Switzerland). Static pressure of the drying chamber was monitored using a digital manometer (Newport Eletronics, PAB41X-C-800-1200, Deckenpfronn, Germany). The manometer was positioned at the bottom of the drying chamber parallel to the air flow at the near left-hand corner, where the influence from turbulence was assumed to be minimal. The manometer, the anemometer and the HygroClip® were connected to a multi-channel benchtop analyzer (Rotronic, HygroLab 2, Bassersdorf, Switzerland). The benchtop analyzer was used together with a notebook for data acquisition. Fuel consumption was measured using an industrial digital balance, where mass reduction was recorded by a data acquisition unit (Hewlett Packard, Agilent 34970A, Palo Alto, Cal. USA). All the above measurements were synchronized and logged at 30-second intervals. Electrical energy consumption was measured with an analog kilowatt-hour meter (electromechanical induction, single-phase, AC). Initial and final mass of the loaded trays were measured. Fruits from trays 5, 9, and 13 (top tray was tray 1) were sampled at 2 ± 0.5 hours intervals. Samples were sealed and kept in a polyethylene bag at approximately 6 °C until laboratory analyses were conducted.

Energy performance To analyze energy performance of the dryer, cumulative and instantaneous indices were used, as suggested by Kudra (2004). Indices calculated were adapted from the International Standard for Determination of Drying Performance (ISO, 1997). Evaporation rate (E') was calculated based on the absolute humidity of the exhaust air (x_x) taking into account the absolute humidity of the ambient air (x_a) and the air mass flow rate (q_m) as shown in Equation 1:

$$E' = \left(x_x - x_a \right) q_m \qquad (1)$$

Thermal power input (P_i) was calculated based on the enthalpy of the air entering the drying chamber (h_i) and the air mass flow rate (Equation 2):

$$P_i = h_i \cdot q_m \tag{2}$$

Thermal energy input (W_i) was obtained from the thermal power (Equation 3):

$$W_i = P_i \cdot t \tag{3}$$

To determine the heat used to evaporate a unit mass of water specific thermal energy consumption (Q_C) was calculated as shown in Equation 4:

$$Q_C = \frac{W_i}{E} \tag{4}$$

Heat loss to the ambient (Q_L) was calculated based on the difference between the thermal energy input (W_i) and the exhaust thermal energy (W_x). Thermal energy output was calculated based on the enthalpy of the exhaust air and the air mass flow rate (Equation 5):

$$Q_L = W_i - W_x \tag{5}$$

Product quality Samples at different drying stages were evaluated on moisture content (*MC*), water activity (a_w) and color. Moisture content was obtained by the static gravimetric method using a convection laboratory oven (Memmert Co., UFB 500, Schwabach, Germany) at 103 °C until reaching constant weight (app. 72 h). Water activity was determined using a water activity meter (Rotronic, AW-DIO, Bassersdorf, Switzerland). Readings were performed with finely chopped samples at 25 °C using a thermostatic chamber. Flesh color was evaluated for three fruits per sample using a colorimeter (Minolta Inc., CR-300, Osaka, Japan). The instrument was set in CIELAB color space and D_{65} illumination. Color values were expressed as *L* (Lightness), a^* (red/green) and b^* (yellow/blue). Each fruit was scanned at two different locations. The a^* and b^* values were converted to hue angle (*H*) using Equation 6:

$$H = \arctan\left(\frac{b^*}{a^*}\right) \tag{6}$$

To analyze homogeneity of the drying chamber temperature at center and corner of trays 3, 7 and 11 were plotted against drying time.

RESULTS AND DISCUSSION

Energy performance In the studied dryer, 14.6 ± 2.5 kg of LPG was required per batch. Each batch yielded 15.3 ± 1.8 kg of dry litchi. Per kilogram of dried litchi produced 0.95 ± 0.05 kg of LPG was consumed. On average 41.0 ± 3.4 MJ of electrical energy was required per batch. Table 1 shows the performance indices and Figure 1 how it changed during the drying process.

Table 1.Average and standard deviation (SD) of performance indices of the dryer.

Performance indices	Unit	Mean	±	SD
Mass of litchi used for trials	kg	89.20	±	28.17
Evaporation mass	kg	73.90	±	26.68
Duration of trials	min	921.9	±	93.4
Evaporation rate (E')	$g\ s^{-1}$	1.35	±	0.42
Fuel consumption	$g\ s^{-1}$	0.27	±	0.02
Electrical energy consumption	$kJ\ s^{-1}$	0.76	±	0.02
Specific fuel consumption	$kg\ kg^{-1}$	0.21	±	0.05
Thermal power consumption (P_i)	kW	10.69	±	0.27
Thermal energy consumption (W_i)	MJ	592.59	±	72.88
Heat loss to the ambient (Q_L)	MJ	192.94	±	31.59
Specific thermal energy consumption (Q_C)	$MJ\ kg^{-1}$	10.32	±	2.68

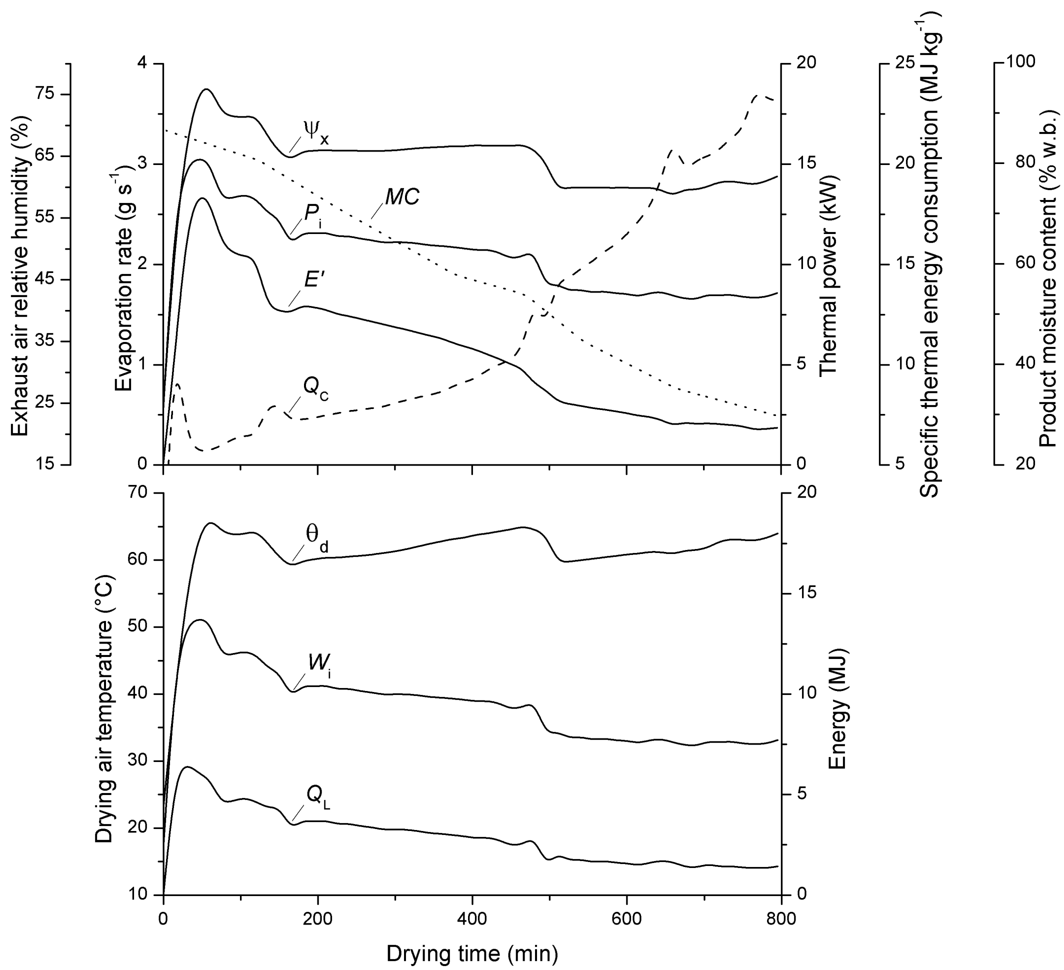

Figure 1. Relative humidity of the exhaust air (ψ_x), product moisture content (*MC*), thermal power input (P_i), evaporation rate (E'), specific thermal energy consumption (Q_C), drying air temperature (θ_d), thermal energy input (W_i) and heat losses to the ambient (Q_L) during the drying process.

Exhaust heat losses is minimum when the relative humidity of the air at the outlet is close to saturation (Kudra, 2004). However, in the studied dryer the highest relative humidity of the exhaust air was 76.7% and it decreased as drying proceeded. Evaporation rate was strongly governed by litchi moisture content and drying air temperature. The absence of a constant evaporation rate at the beginning of the process indicated that the surface of the fruit did not contain free moisture. That is because the litchi membrane performs strong resistance against moisture evaporation (Zhao et al., 1999). The stepwise temperature regime caused the power and energy input to decrease throughout the process. However, this reduction was not as sharp as the reduction of the evaporation, producing a marked increase of the specific thermal energy consumption. This could be mitigated by greater decrease of energy input which is viable by reducing air flow rate. Analysis of the relative humidity of the exhaust air suggests that evaporative capacity would not be jeopardized with gradual reduction of the air flow rate. Regarding heat losses to the ambient, it corresponded to the variation on drying air temperature and might be easily minimized by insulating wall and ducts of the dryer.

Product quality For litchi drying, temperature is the most important factor (Pott et al., 2000). Thus, uniform temperature distribution is required in order to obtain a homogeneous batch. However, vertical and horizontal temperature distribution was found to be non-uniform in the drying chamber as shown in Figure 2. It is believed that this heterogeneity was caused by the air inlet of the drying chamber (two vertical slots), which produced an uneven distribution of the air flow. Temperature differences at the drying chamber affected product quality as shown in Figure 3.

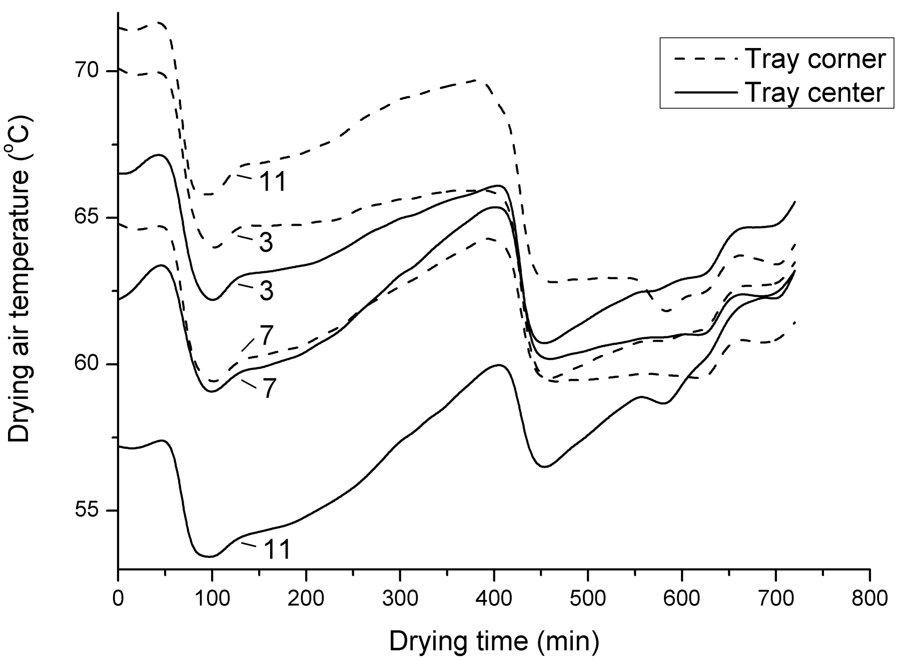

Figure 2. Drying air temperature during the drying process at the center and corner of trays 3, 7 and 11 (top = tray 1).

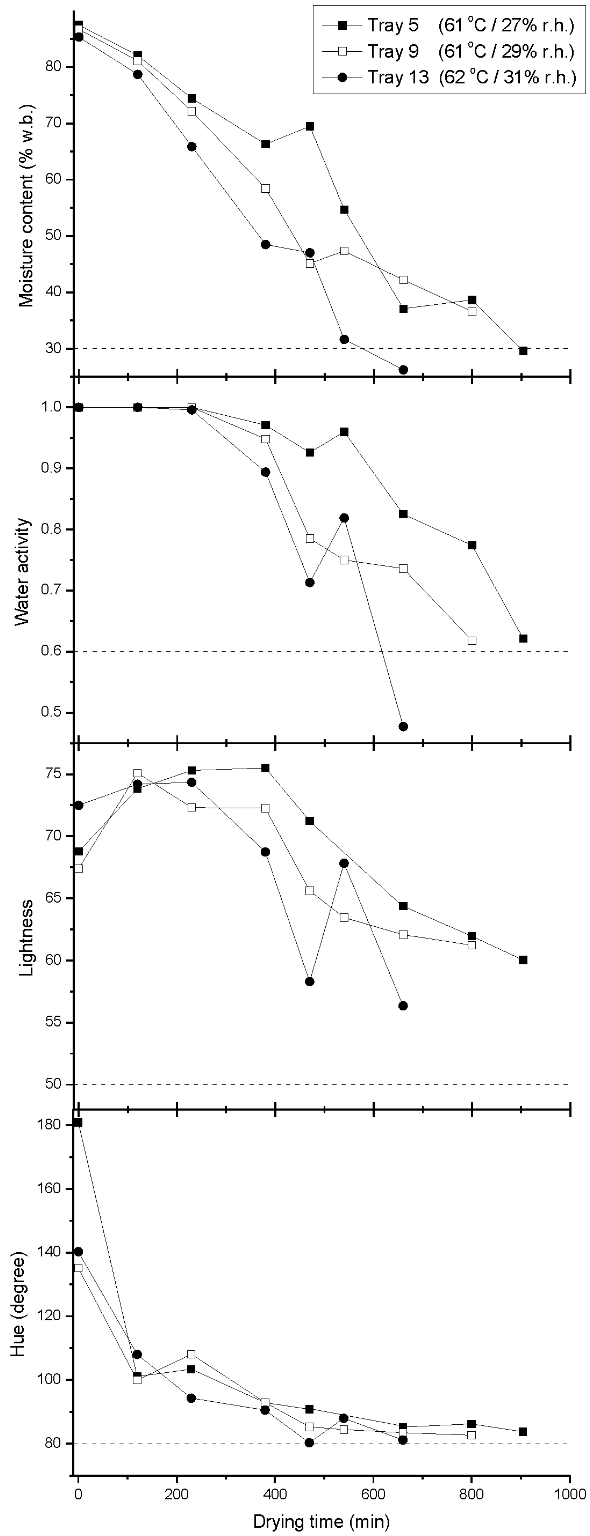

Figure 3. Litchi moisture content (% w.b.), water activity and color changes during the drying process. Values in parentheses are average temperature and relative humidity of drying air. Dashed lines represent reference values from Kuhn (1962) for moisture content, Beuchat (1983) for water activity, Pott et al. (2000) for lightness and Mahayothee et al. (2009) for hue angle.

As shown by the quality analysis presented in Figure 2, initial moisture content of samples was 86.5 ± 1.1% w.b, which steadily decreased during the drying process, meaning drying took place during the falling rate period. Samples on tray 9 of the dryer did not reach the recommended moisture content for safe long-term storage, which should be less than 30% w.b. (Kuhn, 1962). Regarding water activity, the recommended upper limit of $a_w \leq 0.6$ required for storability (Beuchat, 1981) was not achieved by samples on trays 5 and 9. Fresh litchi samples had an average lightness value of 69.6 ± 2.6 and an average hue angle of 152.1 ± 25.0°. During the drying process fruits became darker and hue angle decreased.

CONCLUSION Convection drying requires high energy input because of inefficient air-material heat transfer and energy losses via exhaust air. Litchi drying is a particularly energy-intensive process, due to the high initial moisture content of the fruit and its strong water binding forces. The analysis of the instantaneous indices demonstrated that the main heat losses were via exhaust air. Heat loses to the ambient via dryer walls and ducts were also significant. Exhaust losses could be reduced by decreasing air flow rate or increasing the proportion of air recirculation. A frequency-converter would allow the control of the blower speed and consequently permit gradual reduction of airflow during the drying process. Air recirculation could be controlled by an adjustable size of the dryer's air outlet. Heat loses to the ambient could be reduced by insulation.

To improve batch quality more homogenous drying conditions is required. To realize this, the chamber air inlet should be re-designed for better distribution of air flow. It is believed that simple modifications should improve energy and quality performance of the dryer without impacting manufacturing requirements or equipment price.

Acknowledgements This research is a part of the Collaborative Research Centre SFB 564 ("Research for Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia"), funded by Deutsche Forschungsgemeinschaft Germany (DFG), and co-funded by the National Research Council of Thailand.

REFERENCES

Anupunt P, and Sukhvibul N. 2005. Lychee and longan production in Thailand. Acta Horticulturae (ISHS) 665:53-60.

Beuchat LR. 1981. Microbial stability as affected by water activity. Cereal Foods World 26(7):345-349.

Boeer T, and Schipmann C. 2008. Assessment of Different Value-Chain Upgrading Strategies for Litchi Farmers in Northern Upland Parts in Thailand. Tropentag 2008: International Research on Food Security, Natural Resource Management and Rural Development University of Hohenheim, Stuttgart, Germany.

Chen HB, and Huang HB. 2001. China litchi industry: development, achievements and problems. Acta Horticulturae (ISHS) 558:31-39.

Holcroft DM, and Mitcham EJ. 1996. Postharvest physiology and handling of litchi (Litchi chinensis Sonn.). Postharvest Biology and Technology 9(3):265-281.

Huang X, Subhadrabandhu S, Mitra S, Ben-Aire R, and Stern R. 2005. Origin, history, production and processing. In: Menzel CM, and Maite GK, editors. Litchi and longan: botany, production and uses. Wallingford: CABI International. p 1-24.

ISO. 1997. International Standard 11520-1:1997 Agricultural Grain Drier - Determination of Drying Performance. International Standard: International Organization of Standardization.

Kudra T. 2004. Energy aspects in drying. Drying Technology 22(5):917-932.

Kuhn G. 1962. Dehydration studies of lychee fruit. Proceedings of the Florida State Horticultural Society. p 273-277.

Mahayothee B, Udomkun P, Nagle M, Haewsungcharoen M, Janjai S, and Mueller J. 2009. Effects of pretreatments on colour alterations of litchi during drying and storage. European Food Research and Technology:1-9.

Men'shutina NV, Gordienko MG, Voinovskii AA, and Kudra T. 2005. Dynamic criteria for evaluating the energy consumption efficiency of drying equipment. Theoretical Foundations of Chemical Engineering 39(2):158-162.

Pott I, Bühle M, Mühlbauer W, and Wiriyacharee P. 2000. Drying lychee fruits (Litchi chinensis Sonn.) for preserving quality and vitamin C. Proceedings Tropentag 2000. Stuttgart, Germany.

Precoppe M, Nagle M, Piepho H-P, Mahayothee B, Janjai S, Haewsungcharern M, and Müller J. 2008. Analysis of current practices of litchi drying in small scale industries in Northern Thailand. Proceedings Tropentag 2008. Stuttgart, Germany.

Schreinemachers P, Roygrong S, Potchanasin C, and Berger T. 2008. The Declining Profitability of Litchi Fruit Orchards in Northern Thailand: Can Agricultural Innovations Reverse the Trend? Proceedings Tropentag 2008. Stuttgart, Germany.

Strumiłło C, Jones PL, and Zyłła R. 2007. Energy Aspects in Drying. In: Mujumdar AS, editor. Handbook of industrial drying. 3rd ed. Boca Raton, FL: Taylor & Francis. p 1075-1101.

Subhadrabandhu S. 1992. Status of the tropical fruit industry in Thailand. Acta Horticulturae (ISHS) 292:13-24.

Subhadrabandhu S, and Yapwattanaphun C. 2001. Lychee and longan production in Thailand. Acta Horticulturae (ISHS) 558:49-57.

Tindall HD. 1994. Sapindaceous fruits: botany and horticulture. In: Janick J, editor. Horticultural Reviews. New York: John Wiley & Sons, Inc. p 143-196.

Zhao H, Li C, and Guan Z. 1999. Experimental research on drying characteristics of Litchi. Drying technology 17(9):1915-1925.