Evaluation of PHilMech cabinet dryer for drying mango slices

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Abstract: The performance of PHilMech cabinet dryer in drying mango slices was evaluated in terms of efficiency, product quality and cost. The dryer, originally designed with kerosene burner and rice hull furnace as heat source, was retrofitted with liquefied petroleum gas (LPG) heating system. Its performance was likewise compared with existing dryers of Pangasinan Tropical Fruits Multi-Purpose Cooperative (PTFMPC) in Manaoag, Pangasinan, Philippines. Results showed that mango slices with initial moisture content from 65.4% to 72.4% were uniformly dried in 9.5 to 10 h to final moisture content of 9.6% to 9.7% using an average drying temperature of 53.2°C to 54.2°C using the PHilMech dryer. The LPG heating system had higher heating system efficiency than the rice hull furnace and kerosene burner. It is less costly to operate than kerosene burner but remains costly when compared to Rice hull furnace. Total drying cost increased from 21.59 PhP kg^{-1} of dried mango to 25.29 PhP kg^{-1} when the rice hull furnace was replaced with LPG heating system. On the other hand, a reduction of 4.52 PhP kg^{-1} of dried mango was achieved when the kerosene burner was replaced with LPG heater. Compared to other dryers of PTFMPC, the heating system efficiency of the PHilMech dryer was lower. The PTFMPC dryers have exhaust air recirculation of exhaust air which contributed to lower fuel consumption. The provision of exhaust air recirculation in the PHilMech dryer was therefore recommended to improve its heating efficiency. Sensory evaluation showed no significant difference between dried mango slices from PHilMech and PTFMPC dryers.

Keywords: mango, drying, heating, energy

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1 Introduction

The Philippine Center for Postharvest Development and Mechanization (PHilMech) has developed a cabinet dryer to address a number of problems found in locally fabricated cabinet dryers, such as non-uniform airflow and temperature distribution inside the drying chamber as well as excessive heat loss through cabinet walls (Martinez et al., 2010). The PHilMech dryer was retrofitted with a rice hull furnace, significantly reducing cost of drying (Martinez et al., 2010; Martinez et al., 2008). The dryer was also fitted with kerosene burner with its associated heat exchanger, to provide added flexibility. The PHilMech cabinet dryer has a capacity of 240 kg $batch^{-1}$ of mango slices, with three racks which can accommodate a total of 50 drying trays. The dryer is heated with rice hull furnace with automatic husk feeding and ash unloading mechanisms, temperature controller, heat exchanger and fly ash scrubber (Martinez et al., 2008; Martinez et al., 2009). Performance tests have shown that at rice hull consumption rate of 13.8 to 14.5 kg h^{-1}, the furnace has attained heating efficiencies of 52.2% to 54.8% which were above the 50 percent minimum acceptable level set by Philippine Agricultural Engineering Standards (PAES, 2000). Using this dryer, the drying cost is reduced when kerosene burner is replaced with rice hull furnace. The quality of dried mango also maintains its β-carotene content, passed the standard for maximum allowable microbial load and comparable with current commercial products from the mango processor (Daquila et al., 2008).

Despite of the heat source options offered by the PHilMech cabinet dryer, Pangasinan Tropical Fruits

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Multi-Purpose Cooperative (PTFMPC), Philippines would like to have the dryer retrofitted with liquefied petroleum gas (LPG) heating system, like the other dryers in their processing plant. Compared to rice hull furnace, LPG heating system is more expensive to operate, primarily due to the ever rising cost of fossil-based fuels. However, LPG heating system are easier to manage and more convenient to operate than rice hull furnace. Although the furnace operation is automated, it still requires operator's attention from time to time for other manual activities (Martinez et al., 2008; Martinez et al., 2009). Moreover, since PTFMPC does not own a rice mill, rice hull are hauled from a rice mill about 15 km away and has to be provided with storage space, entailing additional costs. On the other hand, with the current pricing of fossil fuel in the local market, it would be cheaper to use LPG than kerosene. Moreover, kerosene requires heat exchanger, substantially reducing heating system efficiency (Martinez et al., 2008; Daquila et al., 2008) while LPG can be directly fired. Likewise, kerosene flue gas is prone to leak out of the heat exchanger, which can potentially impart particulates and off-odor to the dried product. In contrast, LPG is considered non-toxic, non-corrosive and free of any additives. It has been reported that LPG, being an instantaneous fuel, burns more cleanly than kerosene (D'Sa et al., 2004). Therefore, in this study, the PHilMech cabinet dryer retrofitted with LPG heating system for drying mango slices was evaluated, in terms of drying efficiency, product quality and cost. In addition, the performance of PHilMech cabinet dryer was compared against other LPG-heated cabinet dryers of PTFMPC.

2 Materials and methods

2.1 Modification of PHilMech cabinet dryer and installation of LPG burner

The PHilMech cabinet dryer which was originally heated with kerosene burner and retrofitted with rice hull furnace has an overall dimension of 3.6 m long, 1.25 m wide and 1.8 m high. The drying chamber has three racks and 50 trays, each 1.2 m in length and 0.6 m in width and made of food-grade plastic. The drying chamber and the racks were made of stainless steel. The dryer had three 1.0 m diameter axial fans located before each rack and driven on a single shaft by a 1 hp electric motor. The dryer has a heat exchanger for kerosene burner and for rice hull furnace.

Modifications made on the cabinet dryer include the removal kerosene burner and its heat exchanger inside the drying chamber, the replacement of universal shaft transmission drive system with individual belt and pulley drive system for each fan and the conversion of fixed racks to removable tray racks for easy loading and unloading of mango slices (Figure 1). Test runs without load was conducted after modification to determine whether a single LPG torch-type burner was sufficient to reach the recommended temperature for drying mango slices that ranged from 50°C to 60°C. Thermocouple sensors were installed to monitor the temperature distribution inside the drying chamber.

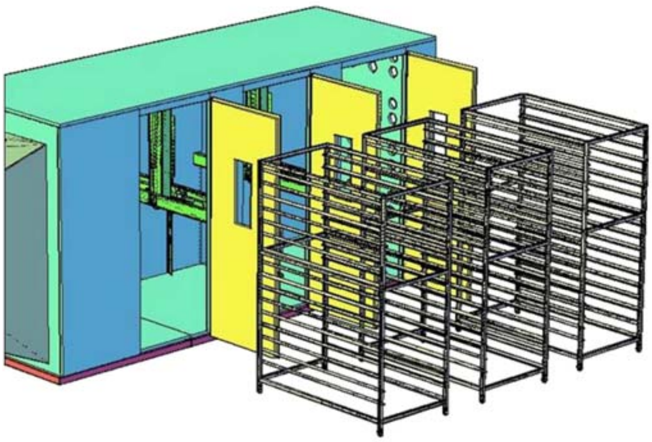
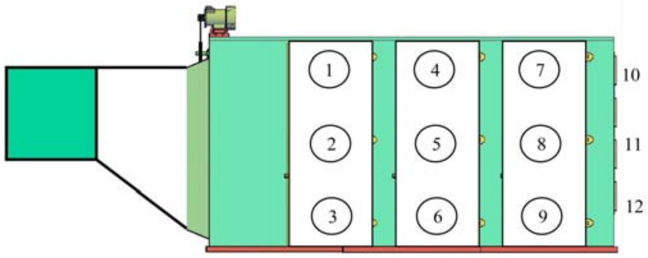


Figure 1 Drying chamber of cabinet dryer with removable tray racks

2.2 Technical performance evaluation of LPG-heated PHilMech cabinet dryer

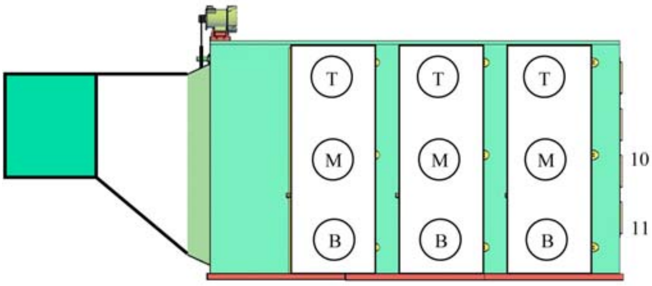
Three drying trials were undertaken using pre-processed mango slices soaked in syrup supplied by PTFMPC. The mango slices were drained to remove excess sugar, and then spread evenly on the plastic trays lined with cheesecloth and finally loaded in the cabinet dryer. The mango slices were dried for 4 to 5 h and then unloaded for partial sweating (tempering) for 1 hour. The mango slices were inverted and dried again for 4 to 5 h until moisture content reached 10 percent. Thermocouple sensors were installed to monitor the temperature distribution inside the drying chamber as shown in Figure

2. Likewise, moisture content distribution inside the drying chamber was monitored by measuring the loss in weight of product being dried in nine trays located inside the chamber as shown in Figure 3.



1. Tray rack 1 Top 2. Tray rack 1 Middle 3. Tray rack 1 Bottom 4. Tray rack 2 Top 5. Tray rack 2 Middle 6. Tray rack 2 Bottom 7. Tray rack 3 Top 8. Tray rack 3 Middle 9. Tray rack 3 Bottom 10. Exhaust air, dry bulb 11. Exhaust air, wet bulb

Figure 2 Thermocouple sensor locations inside the dryer



T = top M = Middle B = Bottom

Figure 3 Location of plastic trays for moisture content determination

Other parameters measured include ambient temperature, ambient relative humidity and drying time. The initial moisture content of test samples was determined by air oven method. The mango slices were weighed and spread evenly on drying trays before being loaded to the dryer. Pre-identified sampling trays at several locations in the dryer were weighed at regular intervals to monitor progress of drying. Drying was stopped when moisture content reached about 10.0 percent. Then the weight of the dried product was determined and its final moisture content measured. Comparison was also made on the heating system efficiency and drying cost using the LPG heater, rice hull furnace and kerosene burner as heat source. The heat utilization rate and heating system efficiency were computed using Equations (1) to (4).

$$\text{Heat utilization rate (kJ kg}^{-1}\text{)} = \frac{\text{Heat supplied to the dryer (kJ h}^{-1}\text{)} \times \text{drying time (h)}}{\text{Total amount of water removed (kg)}} \times 100 \quad (1)$$

$$\text{Heating system of ficiecncy (\%)} = \frac{\text{Heat supplied to the dryer (kJ h}^{-1}\text{)}}{\text{Heat available in the fuel (kJ h}^{-1}\text{)}} \times 100 \quad (2)$$

$$\text{Heat supplied to the dryer (kJ h}^{-1}\text{)} = \frac{(h_2 - h_1) \times \text{Air flow rate (m}^3\text{ h}^{-1}\text{)}}{\text{Specific voulme of air (m}^3\text{ kg}^{-1}\text{)}} \quad (3)$$

where, h_1 = enthalpy of ambient air (kJ kg^{-1}); h_2 = enthalpy of drying air (kJ kg^{-1}).

$$\text{Heat available in the fuel (kJ h}^{-1}\text{)} = FC \times HVLPG \quad (4)$$

where, FC = Fuel consumption (kg h^{-1}); $HVLPG$ = Heating value of LPG (kJ kg^{-1}).

2.3 Technical performance evaluation of PTFMPC cabinet dryers

The cabinet dryers of the PTFMPC were also evaluated and compared with the technical performance of PHilMech dryer. The PTFMPC bigger cabinet dryer (Figure 4) has a capacity of 250 kg of fresh mango slices per batch of drying. The dryer is a rectangular cabinet, with an overall dimension of 478 cm long × 105 cm wide × 220 cm high. It consisted of three doors with three racks, containing 19 trays each. Each tray has a dimension of 90 cm × 100 cm. The vane-axial fan of the dryer is powered by 3 hp electric motor and installed on top of the dryer.

Figure 4 PTFMPC 250 kg capacity LPG-fired cabinet dryer

On the other hand, the PTFMPC small cabinet dryer (Figure 5) has a capacity of 160 kg of fresh mango slices per batch of drying. The small dryer has an overall dimension of 305 cm long × 61 cm wide × 244 cm high. The dryer consists of two doors with two racks containing 21 trays each. The vane axial fan of the dryer is also powered by 3 hp single phase motor. Both the big and small cabinet dryers have exhaust air openings that serve as the entry of ambient air. The opening could be regulated to recycle the heated air inside the drying chamber.

Figure 5 PTFMPC 160 kg capacity LPG-fired cabinet dryer

Dried mango slices from PTFMPC dryer were compared with the mango slices dried in PHilMech dryer. The sensory evaluation was commissioned to the Department of Food Science and Technology, College of Home Science and Industry, Central Luzon State University (CLSU). Nine trained panelists were asked to evaluate the dried mango slices in terms of color, dry appearance, moistness (mouth feel) and toughness (texture) and general acceptability. Quality scoring with nine-point hedonic scale was used to determine the intensity of sensory attributes. Analysis of variance in completely randomized design was used in the analysis of collected data. Duncan's multiple range tests was used to identify significantly different treatment means.

3 Results and discussion

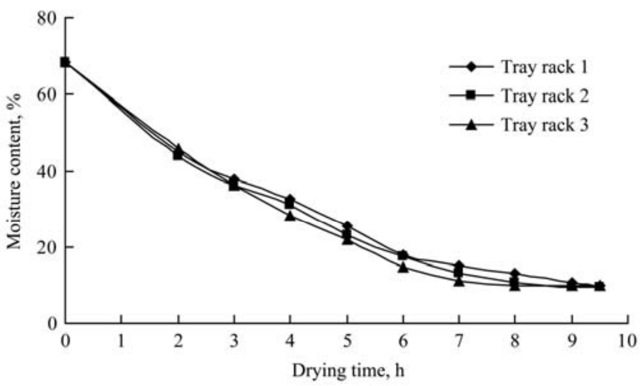
3.1 Technical performance of LPG-fired PHilMech cabinet dryer

The results of drying trials were summarized in Table 1. The dryer was not fully loaded to its maximum load of 250 kg due to limited samples processed and supplied by the project cooperator during each test. The initial moisture content of mango samples from 65.4% to 72.4% was uniformly dried to final moisture content of 9.6% to 9.7% in 9.5 to 10 h at an average temperature ranged of 53.2°C to 54.2°C. LPG used was 1.34 to 1.40 kg h^{-1} of LPG with a heating system efficiency of 91.5% to 93.8%.

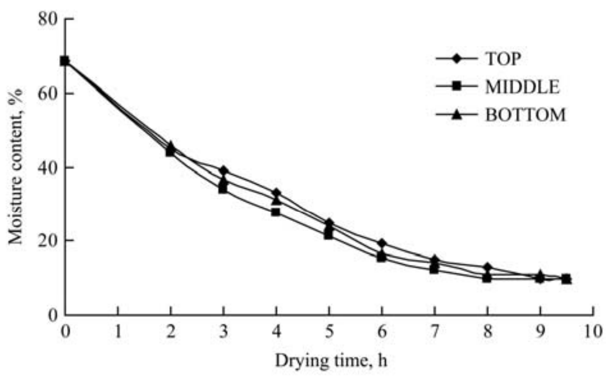
Table 1 Results of drying trials using the PHilMech cabinet dryer retrofitted with LPG burner

Parameter	Trial 1	Trial 2	Trial 3
Initial weight, kg	78.5	79.2	158
Initial moisture content, %	68.5	65.4	72.4
Final weight, kg	27.3	30.3	48.1
Final moisture content, %	9.7	9.6	9.7
Ambient temperature, db, °C	29.7	30.3	31.5
Ambient temperature, bb, °C	25.9	26.7	26.9
Ambient relative humidity, %	74.5	73.0	72.4
Drying temperature, °C	53.2	53.4	54.2
Airflow rate, cfm	1,376	1,363	1,320
Drying time, h	9.5	9.5	10.0
LPG consumption, kg h^{-1} MJ h^{-1}	1.40 68.9	1.36 67.0	1.34 66.0
Heat utilization rate, MJ kg^{-1}	12.0	11.9	5.5
Heating system efficiency, %	93.8	91.2	91.5

The moisture content distributions during the three drying trials were shown in Figures 6 to 8. In general, uniform moisture content was obtained from the nine trays monitored during the three drying trials.

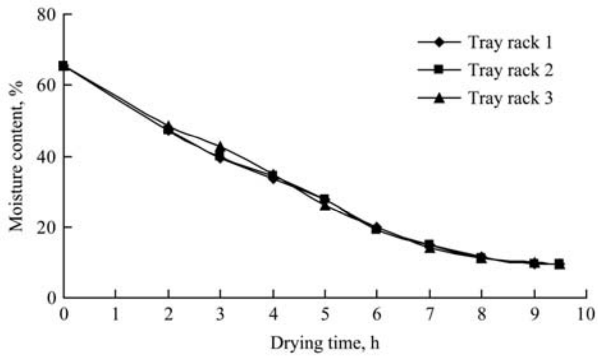


a. At different tray racks

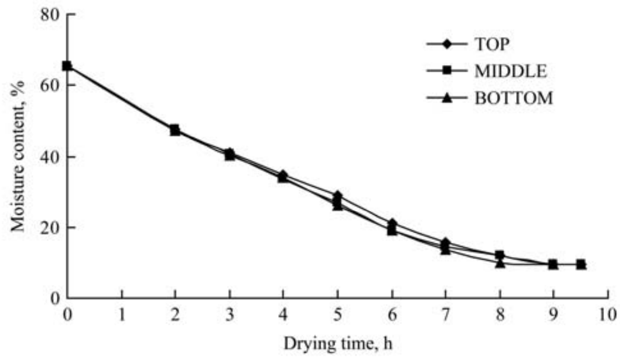


b. At different tray locations during Trial 1

Figure 6 Average moisture content

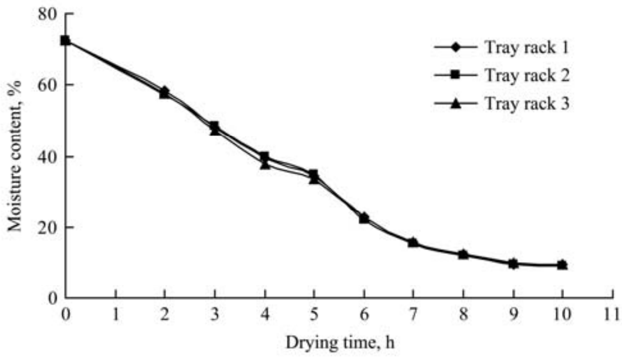


a. At different tray racks

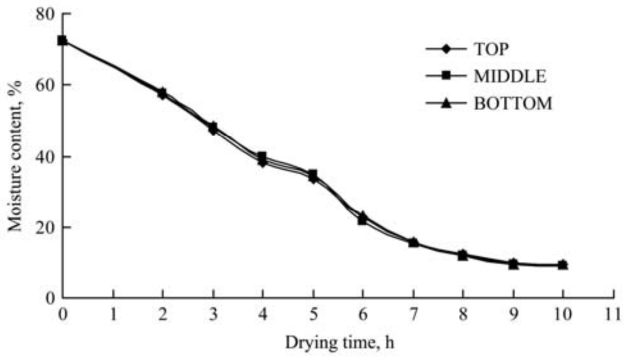


b. At different tray locations during Trial 2

Figure 7 Average moisture content



a. At different tray racks



b. At different tray locations during Trial 3

Figure 8 Average moisture content

The heating system efficiency of the PHilMech cabinet dryer with kerosene burner, rice hull furnace and the LPG burner are summarized in Table 2. Data used in the computation were based on drying test results. Results showed that there is an increase in heating system efficiency when the LPG burner was used. The increase could be attributed to the removal of heat exchanger. The LPG burner could be used to heat directly for drying mango slices, while both the kerosene burner and rice hull furnace needed heat exchanger to avoid contamination of fumes to the product being dried. The rice hull furnace had the lowest heating system efficiency.

Table 2 Heating efficiency of PHilMech cabinet dryer retrofitted with kerosene, rice hull furnace and LPG Heater

Parameters	Kerosene burner	Rice hull furnace	LPG heater
Drying temperature, °C	50.1	57.4	54.2
Ambient temperature, db, °C	32.5	31.4	31.5
Ambient temperature, wb, °C	27.8	27.7	26.9
Ambient relative humidity, %	70.3	76.8	72.4
Fuel consumption, kg h^{-1} MJ h^{-1}	2.4 103.2	17.6 220.0	1.34 66.0
Heat utilization rate, MJ kg^{-1}	5.65	7.49	5.50
Heating system efficiency, %	48.9	28.4	91.5

Tables 3 and 4 summarized the cost of using the cabinet dryer with kerosene burner and rice hull furnace against LPG burner. Data used in the computation were based on drying test results. Originally, the cost of the cabinet dryer heated with kerosene burner was 400,000.00 PhP. The cost of the cabinet dryer increased to 550,000.00 PhP when retrofitted with rice hull furnace.

Table 3 Assumptions used in the comparison of drying cost when using the cabinet dryer with kerosene, rice hull and LPG as fuel

Item	Kerosene	Rice hull	LPG
Number of days in operation per year	240	240	240
Total batches per year	240	240	240
Drying time per batch, h	10	10	10
Weight of dried mango per batch, kg	60	60	60
Investment cost, PhP	400,000	550,000	375,000
Interest on investment, %	16	16	16
Repairs and Maintenance, %	5	5	5
Taxes and insurances, %	1	1	1
Economic life, years	15	15	15
Salvage value, %	0	0	0
Operator's wage per batch, PhP	225	345	225
Total dried mango per year, kg	14,400	14,400	14,400

Note: PhP 1.0 = 0.020 US Dollar.

Table 4 Comparison of drying cost when using the cabinet dryer with kerosene, rice hull and LPG as fuel

Item	Kerosene	Rice hull	LPG
Fixed Costs			
Depreciation, PhP	26.666.67	36.666.67	25,000.00
Interest on investment, PhP	32,000.00	44,000.00	30,000.00
Repairs and maintenance, PhP	20,000.00	44,000.00	18,750.00
Taxes and insurance, PhP	4,000.00	5,500.00	3,750.00
Total fixed cost, PhP	82,666.67	130,166.67	77,500.00
Fixed cost per kg, PhP	5.74	9.04	5.38
Operating Costs			
Operator's wage per kg, PhP	3.75	5.75	3.75
Electricity cost			
Power requirement, kW	1.76	2.53	1.76
Power consumption per batch, kWh	17.60	30.36	17.60
Cost per kWh, PhP	8.50	8.50	8.50
Cost per kg, PhP	2.49	4.30	2.49
Fuel cost			
Fuel consumption, L/h (bag/h)	2.40	2.50	1.37
Fuel cost, PhP/L (PhP/bag)	44.57	5.00	60.00
Cost per kg, PhP	17.83	2.50	13.67
Operating cost per kg, PhP	24.07	12.55	19.91
Total Costs			
Total costs per kg, PhP	29.81	21.59	25.29

Note: PhP 1.0 = 0.020 US Dollar.

The cost of the cabinet dryer was reduced to 375,000.00 PhP when retrofitted with LPG heater due to relatively lower cost of LPG heater and the removal of heat exchanger. However, due to substantial increase of fuel cost, the total operating cost when using LPG burner significantly increased from 12.55 PhP kg^{-1} (when using rice hull furnace) to 19.91 PhP kg^{-1} and reduced from 24.07 PhP kg^{-1} when using kerosene burner. The total drying cost of using LPG burner increased from 21.59 PhP kg^{-1} (when rice hull furnace) to 25.29 PhP kg^{-1} and would slightly reduce the drying cost of 29.81 PhP kg^{-1} when kerosene was used as source of heat to a cabinet dryer.

3.2 Comparison of PHilMech cabinet dryer with PTFMPC cabinet dryers

The result of the evaluation was summarized in Table 5. Results showed that the heating system efficiency of both the small and big PTFMPC dryers was higher compared to PHilMech cabinet dryer. This was mainly due to their slightly higher airflow rates than PHilMech dryer and the provision of air drying recycling system of the PTFMPC dryers. Although higher airflow rates would insure better air distribution, it also resulted to lower fuel consumption rates compared to PhilMech cabinet dryer.

Table 5 Results of drying trials using the PHilMech cabinet dryer retrofitted with LPG heater

Parameter	PHilMech dryer	PTFMPC dryer (big)	PTFMPC dryer (small)
Initial weight, kg	158.0	171.0	105.0
Initial moisture content, %	72.4	60.5	62.5
Final weight, kg	48.3	74.7	43.6
Final moisture content, %	9.7	9.6	9.6
Ambient temperature, Db, ^oC	31.5	32.9	32.5
Ambient temperature, Wb, ^oC	26.9	28.8	28.4
Ambient relative humidity, %	72.4	74.1	73.9
Drying temperature, ^oC	54.2	55.6	55.4
Airflow rate, cfm	1320.0	1375.0	1350.0
Drying time, h	10.0	10.0	10
LPG Consumption, kg h^{-1} MJ h^{-1}	1.34 66.0	1.28 63.0	1.25 61.6
Heating value, MJ kg^{-1}	49.3	49.3	49.3
Heat utilization rate, MJ kg^{-1}	5.50	6.43	9.69
Heating system efficiency, %	91.5	98.2	96.7

The results of the sensory panel evaluation were summarized in Table 6. Statistical analysis revealed that mango samples dried from the three dryers were statistically indistinguishable in terms of color, dry appearance, moistness (mouth feel) and toughness (texture).

Table 6 Mean scores of appearance and textures of the dried mangoes

Source	Color[1]	Dry Appearance[2]	Moistness (Mouth feel)[3]	Texture (Toughness)[4]
PHilMech Trial 2	6.0[a]	5.8[a]	5.2[a]	5.3[a]
PHilMech Trial 3	5.7[a]	5.0[a]	5.4[a]	5.2[a]
PTFMPC Commercial	6.3[a]	4.3[a]	4.8[a]	5.4[a]

Note: Means with same letter superscript within a column were not significantly different at 5% level of significance. 1 where 9 = extremely dark yellow; 1= very high yellow, 2 where 9 = very dry; 1 = very moist, 3 where 9 = very dry; 1= very moist, 4 where 9 = very chewy; 1 = very tender.

The general acceptability scores of the three dried samples were shown in Table 7. Statistical analysis revealed that the levels of general acceptability of the mango slices dried in PHilMech cabinet dryer and the commercial samples obtained from PTFMPC were not significantly different.

Table 7 Mean scores of general acceptability of the three dried samples

Source	General Acceptability
PHilMech Trial 2	7.3[a]
PHilMech Trial 3	6.2[a]
PTFMPC Commercial	5.7[a]

Note: Means with same letter superscript within a column were not significantly different at 5% level of significance. Where 9 = extremely like; 1 = extremely dislike.

4 Summary, conclusion and recommendations

The PHilMech cabinet dryer is originally operated using either rice hull or kerosene as heat source for drying mango slices. However, despite of the heat source flexibilities offered by the PHilMech cabinet dryer, Pangasinan Tropical Fruits Multi-Purpose Cooperative (PTFMPC) requested that the dryer should be retrofitted with LPG heating system. Other modifications made on the cabinet dryer include the removal of the heat exchanger, replacement of the universal shaft transmission drive system with individual drive system for each fan, and the conversion of fixed racks to removable tray racks for easy loading and unloading.

Mango slices with initial moisture content ranging from 65.4% to 72.4% could be uniformly dried in 9.5 to 10 hours down to final moisture content of 9.6% to 9.7% using an average drying temperature of 53.2°C to 54.2°C. The LPG burner had higher heating system efficiency than rice hull furnace and kerosene burner due to the removal of heat exchanger of the dryer. The LPG burner was more expensive to operate than rice hull furnace but less expensive than kerosene burner. The total drying cost increased from 21.59 to 25.29 PhP kg^{-1} of dried mango when the rice hull fed furnace was replaced, and reduced from 29.81 PhP kg^{-1} of dried mango when kerosene burner was replaced with LPG burner.

In terms of sensory quality, dried mango slices from the PHilMech cabinet dryer was comparable with current commercial products being produced by the project cooperator.

Compared to the other PTFMPC dryers, the heating system efficiency of the PHilMech cabinet dryer was lower. This was attributed to the lower airflow rates and the provision of drying air recycling system in the PTFMPC dryers, which also resulted to lower fuel consumption. The provision of exhaust air recirculation in the PHilMech cabinet dryer is therefore recommended to improve its heating efficiency and reduce its fuel consumption.

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